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TITLE:

IMPROVED METHOD FOR
DETECTION OF ATP

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IMPROVED METHOD FOR DETECTION OF ATP

CROSS REFERENCE TO RELATED APPLICATIONS

5 This non-provisional application claims priority to U.S. provisional application [Docket Number 10743/4] entitled IMPROVED METHOD FOR MEASUREMENT OF ATP, filed on February 16, 2001. The provisional application lists Keith Wood, Rita Hannah, and Rich Moravec as inventors.

FIELD OF THE INVENTION

10 The present invention relates generally to the fields of cell biology and molecular biology. In particular, this invention relates to methods, compositions and kits for improving the detection and quantitation of ATP.

BACKGROUND OF THE INVENTION

15 Advances in the biological, biomedical and pharmaceutical sciences have accelerated the pace of research and diagnostics unparalleled to the past. With whole genome sequences becoming quickly and successively available, the assembly of large libraries of small molecules, and the ability to move pharmaceutical development, clinical diagnostic tests and basic research from a reductionist to a whole system approach demands assays that facilitate high throughput analyses. Molecules no longer need to be singly analyzed for their effects on a lone process; instead, the effects of many molecules on several biological systems can be studied simultaneously—if appropriate, fast, reliable, and accurate assays are available.

20 Preferred bioassays that assist in evaluating cellular health are those that detect and quantify adenosine triphosphate (ATP). Hydrolysis of ATP powers many of a cell's biochemical processes. Healthy, viable cells are rich in ATP; dead or dying cells are ATP-poor.

25 Efficient, reliable and accurate assays for cell viability can be used to rapidly discover cytotoxic agents or cell proliferation agents and determine the cytotoxic effect or cell proliferation effect of agents on cells. Cancer pharmaceutical research often endeavors to identify compounds that selectively kill quickly dividing cells—a

primary characteristic of cancer cells. While some effective anti-cancer cytotoxic compounds have been identified; innumerable potentially more valuable compounds await identification. High throughput screens of compound libraries, coupled with efficient cell viability assays, can swiftly identify such compounds. In some systems of the body, controlled cell death is crucial for appropriate function. For example, immune system development—a continual process—depends on apoptosis (programmed cell death). The discovery of drugs to treat immuno-related dysfunctions often depends on determining cell viability. The efficacy of a candidate compound on cell viability can be assayed by detecting ATP, since ATP production is only realized in metabolically active (live) cells and residual ATP in a cell is degraded upon cell death, particularly quickly in non-apoptotic (necrotic) cell death. Assay systems that not only facilitate the evaluation of a substance on cell viability, but also permit high throughput screens that can rapidly test thousands of compounds, streamline new drug discovery.

In clinical settings, diagnostic tests on large numbers of samples are facilitated when simple, accurate and safe assays are used. Disease treatments can then be more readily determined and instituted.

With the availability of whole genome sequences, the identification of gene products that affect ATP production, either indirectly or directly, is made possible, and high throughput screens to identify such proteins are facilitated by simple, fast, accurate and reliable ATP assays.

ATP assays are valuable for innumerable types of measurements for which it is important to determine the presence or absence of microbes or to determine the amount of microbial contamination present, *e.g.*, determining microbial contamination of end products, hygiene monitoring, effectiveness of biocides, success of biological waste treatment process, and the like.

ATP assays depend on reporter molecules or labels to qualitatively or quantitatively monitor ATP levels. Reporter molecules or labels in such assay systems have included radioactive isotopes, fluorescent agents, and enzymes, including light-generating enzymes such as luciferase. Desirable characteristics of any reporter molecule systems include safe, quick and reliable application and

detection. Luminescent systems are among the most desirable since they are exceptionally safe and sensitive.

Light-generating enzymes have been isolated from certain bacteria, protozoa, coelenterates, mollusks, fish, millipedes, flies, fungi, worms, and crustaceans. Those enzymes isolated from beetles, particularly the fireflies of the genera *Photinus*, *Photuris*, and *Luciola*, and from click beetles of genus *Pyrophorus*, have found widespread use in reporter systems. In many of these organisms, enzymes such as luciferases catalyze oxido-reductions in which the free energy change excites a substrate molecule to a high-energy state. When the excited molecule returns to the ground state, visible light is emitted, *i.e.* "bioluminescence" or "luminescence". Among the assay systems in which bioluminescence has been employed to monitor or measure ATP are those in which the activity of an ATP-dependent bioluminescent enzyme, *e.g.* a beetle luciferase, is exploited.

When luciferase is combined with a sample for the purpose of detecting ATP, it is typically desirable to inhibit ATPases endogenous to the sample as well as enzymes that generate ATP, thus assuring that the ATP detected corresponds to the actual amount of ATP in a sample at a desired time. Many ATPase inhibitors are known, including detergents, especially detergents that are positively charged. However, most ATPase inhibitors are effective in not only eliminating ATPase function endogenous to the sample (*e.g.*, a cell or cell population), but also ATPases that may be used as the reporter molecule, such as luciferase. Additionally, to counter ATP production, inhibitors of enzymes that phosphorylate, such as kinases, are desirable. However, these inhibitors, such as sodium fluoride (NaF), might also affect luciferase function. A challenge to improving ATP detection in a sample using luciferase depends on methods or compositions that substantially decrease or eliminate ATPase activity and ATP-generating activity endogenous to the sample, thereby stabilizing the amount of ATP present in the sample to that present when the composition is added, without confounding luciferase function.

There are multiple variations of cellular ATP detection methods currently used, all of which act in a stepwise manner. Some such methods first lyse the cells and inactivate the ATPase activity endogenous to the sample (*e.g.*, by increasing sample pH), then neutralize the ATPase inhibitor, thereby converting the environment

of the sample to one favorable to luciferase activity prior to adding the luciferase and detecting luminescence. Other such methods combine the neutralization of the ATPase inhibitor with the addition of luciferase. There are no ATP detection systems that provide a composition or method capable of inactivating endogenous ATPase activity and detecting luciferase activity in the same environmental milieu. Therefore, current assays that use luminescence to detect ATP are handicapped by the need for successive, time-consuming steps.

The present invention provides compositions with properties of enhanced stability comprising a luciferase and one or more ATPase inhibitors and further provides methods using these novel compositions to detect ATP in a sample by reducing the steps of cell lysis, endogenous ATPase inhibition, and substrate and luciferase addition to a single step that is then followed by detection of luminescence. Because embodiments of the invention significantly reduce the time and effort of luciferase-mediated detections of ATP by eliminating the need to neutralize ATPase inhibitor activity before adding luciferase, high throughput assays can finally be efficiently realized.

SUMMARY OF THE INVENTION

The invention is drawn to methods, compositions and kits that are used to detect and quantify ATP levels in a sample. The method comprises adding to a sample a composition ("reagent composition") comprising a luciferase enzyme and an ATPase inhibitor, and detecting luminescence produced in the sample by the conversion of a substrate into a luminescing compound by luciferase. The reagent composition has properties of enhanced stability, thereby eliminating the traditional step of inhibiting ATPases endogenous to a sample before adding luciferase enzyme to the sample. Thus, although luciferase functions as an ATPase, while in the reagent composition it is resistant to the effects of an ATPase inhibitor also present in the reagent composition. Such stable reagent compositions facilitate many ATP detections in a sample over a long period of time as well as detection of ATP in many samples over a long period of time.

In general, the methods comprise adding a composition ("reagent composition") comprising a luciferase (such as exemplified by, but not limited to,

SEQ ID NOs: 1-4) and one or more ATPase inhibitors to a sample and detecting luminescence, wherein the activity of the reagent composition has enhanced stability [*i.e.*, the reagent composition is capable of maintaining at least about 30%, more preferably at least about 60% activity (as measured by luminescence when the reagent composition is combined with the sample) for at least one hour, even more preferably at least 70%, 80%, 90%, 95%, 99% or greater activity for at least one hour, still more preferably for at least two hours and even more preferably for at least four hours relative to the reagent composition's activity when it is created, *i.e.*, just after (0 to 10 minutes) the luciferase enzyme is combined with an ATPase inhibitor], and wherein the ATPase inhibitor is present in the reagent composition at a concentration sufficient to reduce ATPase activity endogenous to the sample by at least about 25%, more preferably at least about 30%, more preferably at least about 40%, even more preferably 50%, 60%, 70%, 80%, 90%, 95%, or 99% or greater relative to the sample's ATPase activity in the absence of the ATPase inhibitor. The reagent composition may be admixed before use by adding a solution comprising one or more ATPase inhibitors to a lyophilized luciferase.

Loss of stability is defined as irreversible loss of activity. The reagent composition loses stability over time and the amount of activity lost varies depending on the particular luciferase, ATPase inhibitor and, when present, enzyme stabilizing agent used. Preferably the stability of the reagent composition is demonstrable in the temperature range of about 20°C to about 37°C. Although the methods of the invention may be used with a sample containing any amount of ATP, it is preferable to use a sample containing a non-saturated amount of ATP (*i.e.*, a range where luminescence is linearly proportional to the concentration of ATP).

The luminescence generated by a luciferase reaction is typically detected with a luminometer although other detection means may be used. The presence of light greater than background level indicates the presence of ATP in the sample. The background level of luminescence is typically measured in the same matrix in which the sample exists, but in the absence of the sample. Suitable control reactions are readily designed by one of skill in the art. Preferred luciferases used in the compositions and methods of the invention generate a stable signal, *i.e.*, they yield enhanced duration of luminescence in a luciferase reaction defined as less than 50%

loss of luminescence per hour relative to the luminescence at the time the luciferase reaction was initiated. Preferred luciferases of the invention allow for multiple analyses of a sample over time or analysis of many samples over time, one hour after the luciferase is combined with the ATPase inhibitor, more preferably two hours and most preferably four hours or more. Optionally, the luciferases used in the compositions and methods of the invention have enhanced thermostability properties.

Quantifying the amount of emitted light also quantifies the amount of ATP in a sample, and thereby the quantity of living cells. Quantitative ATP values are realized, for example, when the quantity of light emitted from a test sample is compared to the quantity of light emitted from a control sample or to a standard curve determined by using known amounts of ATP and the same luciferase, substrate, and reaction conditions (*i.e.* temperature, pH, *etc.*). It is understood that quantification involves subtraction of background values. Qualitative ATP values are realized when the luminescence emitted from one sample is compared to the luminescence emitted from another sample without a need to know the absolute amount of ATP present in the samples, e.g., a comparison of samples in the presence or absence of a test compound. Many such experiments can readily be designed by one of ordinary skill in the art.

Examples of ATPase inhibitors include detergents, preferably detergents with charged groups such as cationic detergents [*e.g.*, DTAB (dodecyltrimethylammonium bromide), CTAB (cetyltrimethylammonium) and BDDABr (benzyltrimethylammonium bromide)], anionic detergents (*e.g.*, SDS and deoxycholate), and zwitterionic detergents (*e.g.*, sulfobetaine 3-10). To facilitate the method, a substrate for the luciferase, such as luciferin, may be included in the reagent composition. Other embodiments of the reagent composition further comprise a compound, such as NaF, that prevents an increase in ATP levels in the sample over time. Other compounds that prevent an increase in ATP levels in the sample include vanadate and paranitrophenylphosphate. Still other embodiments of the reagent composition further comprise a buffer and magnesium. One of skill in the art knows that other cations, such as manganese and calcium, may be suitable substitutes for magnesium.

5 The reaction composition may also comprise an enzyme stabilizing agent. The enzyme stabilizing agent can be any compound that stabilizes the luciferase from degradation. Suitable enzyme stabilizing agents include proteins (such as bovine serum albumin or gelatin) or detergents (preferably non-ionic detergents, most preferably THESIT).

10 Because the presence of ATP (or a particular ATP:ADP ratio) is a property of living cells, the invention is also directed to detecting and quantifying live cells in a sample using the above-described compositions. The amount of luminescence then correlates to the number of viable cells within a population, usually measured by lysing an aliquot of a population of cells of interest while applying the invention or extracting the ATP from a cell or population of cells.

15 Further, the present invention is useful for determining the effect of small molecules (including organic and inorganic molecules and synthetic and naturally occurring molecules) on living cells, which in turn allows the assessment of whether the small molecule may function as a pharmaceutical. Thus, the invention is also directed to methods that determine the effect of a compound on a first population of cells by contacting the first population of cells with a concentration of the compound and then at a later time contacting the first population of cells with a composition of the invention, detecting and comparing the amount of luminescence in the first population to an amount of luminescence in a second population of cells. The second population of cells may be contacted with a concentration of the compound that is less than the concentration contacting the first population of cells or with no compound. A lesser amount of luminescence detected from the first population compared to the second population may indicate that the compound comprises a cytotoxic agent. In this way, 25 cytotoxic reagents may be discovered. Similarly, the invention is useful for discovering cell proliferation reagents, *i.e.*, compounds that stimulate cell growth. Using the above example, a lesser amount of luminescence detected from the second population compared to the first population may indicate that the compound comprises a cell proliferation agent. The invention is useful for comparing the effects of different compounds at the same concentration on cells. The invention is also 30 useful for comparing the effect of a compound on different types of cells. One of skill in the art may develop many other such assays for which the invention is useful.

The invention also assembles the elements of the invention into kits. Such kits are designed to determine the presence of ATP in a sample, *e.g.* measuring cell viability within a population of cells, or determining the effects of compounds on cells. Kits can be multifunctional such that more than one purpose can be realized. In one embodiment, a kit that is used to detect ATP in a sample may comprise lyophilized luciferase in one container, while another container contains reconstitution buffer with one or more ATPase inhibitors. The ATPase inhibitors may be detergents, preferably detergents with ionic groups including cationic detergents (preferably DTAB or BDDABr), anionic detergents (preferably SDS or deoxycholate) or zwitterionic detergents (preferably sulfobetaine 3-10) or a combination thereof.

The kit may also supply a luciferase substrate, such as luciferin. The kit may also supply magnesium or other cations such as manganese or calcium. To facilitate the use of control experiments with known concentrations of ATP, such as in embodiments of the kits that are used to quantify ATP in a sample, a container that has ATP may also be supplied in such kits. The kit may also supply a compound that prevents an increase in the amount of ATP in the sample over time (*e.g.*, NaF). The kit may also supply a cell-lysing agent or an ATP extracting agent (*e.g.*, TCA, DMSA, CTAB, ethanol, and the like). The kit may also supply a buffer. The kit may also supply an enzyme stabilizing agent, *e.g.*, BSA or gelatin or THESIT.

A preferred embodiment of the kit contains components which, when combined, generate a reagent composition that (i) maintains at least about 30% (preferably at least about 60%, even more preferably at least 70%, 80%, 90%, 95%, 99%) activity for at least about one hour (preferably at least two hours, more preferably four hours), as detected by luminescence when the reagent composition is combined with a sample, and relative to the reagent composition's activity just after it is assembled (*i.e.*, 0 to 10 minutes after the component comprising luciferase is combined with the component comprising an ATPase inhibitor) and (ii) reduces at least about 25% or at least about 30%, (preferably at least about 40%, even more preferably at least about 50%, 60%, 70%, 80%, 90%, 95%, 99% or any increment therein) of the ATPase activity that is endogenous to the sample relative to the sample's ATPase activity in the absence of the ATPase inhibitor.

The component comprising an ATPase inhibitor may comprise greater than one ATPase inhibitor wherein they are present in the reagent composition at a concentration such that their combined effect reduces at least about 25% or at least about 30%, (preferably at least about 40%, even more preferably at least about 50%,
5 60%, 70%, 80%, 90%, 95%, 99% or any increment therein) of the ATPase activity that is endogenous to the sample relative to the sample's ATPase activity in the absence of the ATPase inhibitor and when allow for the reagent composition.

Most preferably the kit comprises a container comprising a buffered detergent solution, said buffered detergent solution at a pH in the range of about pH 6.0 to about
10 pH 8.0, and said buffered detergent solution comprising DTAB whose concentration in the reagent composition is in the range of about 0.05% to about 2% (w/v) and optionally comprising NaF whose concentration in the reagent composition is in the range of about 1 mM to about 20 mM and optionally comprising THESIT whose concentration in the reagent composition is in the range of about 1% to about 5%.

The kit additionally comprises a separate container comprising lyophilized luciferase,
15 preferably a luciferase with the sequence of SEQ ID Nos: 1, 2, 3, or 4, most preferably SEQ ID Nos: 2 or 4. Preferably the luciferase, when combined with the buffered detergent solution creating the reagent composition, is at a concentration of 1 µg/ml or greater, more preferably at a concentration of 80 µg/ml or greater.

20 Preferably, the container comprising lyophilized luciferase further comprises lyophilized luciferin. Optionally, the kit further comprises instructions for use of the kit for the purpose of measuring ATP.

BRIEF DESCRIPTION OF THE DRAWINGS

25 FIG.1 is a graph illustrating the effect of increasing concentrations of various nonionic and zwitterionic detergents on relative ATPase activity in a sample.

FIG.2 is a graph illustrating the effect of increasing concentrations of various cationic
30 or anionic detergents on relative ATPase activity in a sample.

DETAILED DESCRIPTION OF THE INVENTION

5 The present invention provides compositions with properties of enhanced stability comprising a luciferase and one or more ATPase inhibitors. The invention further provides compositions with properties of enhanced stability comprising a cell lysing agent, a luciferase and one or more ATPase inhibitors. The invention further provides methods using these novel compositions to detect ATP in a sample by reducing the steps of cell lysis, endogenous ATPase inhibition, and substrate and luciferase addition to a single step that is then followed by detection of the resulting luminescence. Alternatively, cell lysis may be replaced with extraction of ATP from a cell or a population of cells. Preferably the luminescence resulting from the combination of a composition of the invention with a sample has an extended duration, *i.e.*, diminished by less than about 50% per hour relative to the luminescence just after the composition is combined with the sample. The process of the invention significantly reduces the time and effort of luciferase-mediated detection of ATP in a sample by eliminating the need to neutralize ATPase inhibitor activity before adding luciferase.

20 There are multiple variations of ATP detection methods currently used, all of which act in a stepwise manner. Some such methods first lyse the cells and inactivate the ATPase activity endogenous to a sample (*e.g.*, by increasing sample pH), and then neutralize the ATPase inhibitor, thereby converting the environment of the sample from one favoring ATPase inhibition and unfavorable to luciferase activity to one favorable to luciferase activity prior to adding luciferase and measuring luminescence. Similar methods exist in which the environment of the sample is converted to one favoring luciferase activity at the same time that the luciferase enzyme is added.

25 There are no ATP detection systems that provide a composition or method capable of inactivating endogenous ATPase activity and allowing for luciferase activity in the same environmental milieu. And there are no ATP detection systems that provide a composition or method capable of lysing cells or extracting cellular ATP, inhibiting ATPase activity endogenous to a sample and allowing for luciferase activity in the same environment. Therefore, current assays that use luminescence to detect ATP are handicapped by the need for successive, time-consuming steps.

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In preferred embodiments, the present invention reduces to a single step the manipulations needed for ATP detection in a sample, prior to luminescence measurement. In the single-step ATP assay of the invention, all of the necessary components of the ATP-dependent enzyme (*e.g.*, luciferase), such as the enzyme, substrates, and ATPase inhibitors are comprised within a reagent composition and are added to a sample at once. In some embodiments the reagent composition further comprises a cell lysing agent or an agent for ATP extraction from cells. In some embodiments, a component of the reagent composition is a compound (*e.g.*, NaF) that prevents an increase in ATP levels in the sample over time. The mechanism by which ATP levels are increased over time in certain samples, such as a cell lysate prepared with lymphoid cells (*e.g.*, Jurkat cells), is not well understood, but it possibly results from the activity of a kinase enzyme endogenous to the sample. In some embodiments, a component of the reagent composition is an enzyme stabilizing agent.

A. Definitions

Unless defined otherwise, all technical and scientific terms have the same meaning as is commonly understood by one of skill in the art to which this invention belongs. All cited patents and publications are incorporated by reference in their entirety unless otherwise noted.

The nomenclature recommendations of Demerec et al., 1966, where these are relevant to genetics, are adapted herein. To distinguish between genes (and related nucleic acids) and the proteins that they encode, the abbreviations for genes are indicated by *italicized* (or underlined) text while abbreviations for the proteins start with a capital letter and are not italicized. Thus, *luc* or Luc refers to the *luciferase* nucleotide sequence that encodes luciferase polypeptide or Luc.

An "isolated" or "purified" luciferase is one that has been identified and separated and/or recovered from a component of its natural environment.

The term "sample" as used herein, is used in its broadest sense. A sample is a composition suspected of containing ATP that is analyzed using the invention. While often a sample is known to contain or suspected of containing a cell or a population of cells, optionally in a growth media, or a cell lysate, a sample may also be a solid surface, (*e.g.*, a swab, membrane, filter, particle), suspected of containing an attached

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$$\% \text{ amino acid sequence identity} = (X/Y) \cdot 100$$

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B. Reagent composition

The reagent composition of the present invention comprises one or more ATPase inhibitors, preferably a detergent, and a non-endogenous ATP-dependent enzyme, wherein the composition is capable of maintaining at least about 30% enzymatic activity for at least about one hour, preferably at least about 2 hours, more preferably at least about 4 hours, compared to its activity just after (0 to 10 minutes) the enzyme is combined with the ATPase inhibitor, and wherein the one or more ATPase inhibitors are present in the composition at a concentration sufficient to collectively reduce ATPase activity endogenous to the sample by at least about 25%, more preferably at least about 30%, 40%, 50%, 60%, 70%, 80%, 90%, 95% or 99% or any increment therein relative to the ATPase activity endogenous to the sample in the absence of the ATPase inhibitor. In preferred embodiments of the invention, the non-endogenous ATP-dependent enzymes are luciferases.

1. Luciferases

Luciferase enzymes whose catalytic products include light, offer sensitivity, a detectable product, and enable easy measurement of ATP. However, any luminescence-producing enzyme that is ATP-dependent may be used in the methods and compositions of the present invention.

At their most basic level, luciferases are defined by their ability to produce luminescence. More specifically, a luciferase is an enzyme that catalyzes the oxidation of a substrate, luciferin, thereby producing oxiluciferin and photons.

To date, five classes of luciferases have been identified (Jones et al., 1999; Thomson et al., 1997). Of these, beetle luciferases, such as that of the common firefly (family Lampyridae), form a distinct class with unique evolutionary origins (McElroy et al., 1969; White et al., 1969; White et al., 1975). Beetle luciferases are often referred to as firefly luciferases in the literature; however, firefly luciferases are actually a subgroup of the beetle luciferase class. Beetle luciferases may be purified from the lanterns of the beetles themselves or from protein expression systems well known in the art (Baldwin and Green, 2000; Beny and Dolivo, 1976; Branchini et al., 1980; Filippova et al., 1989).

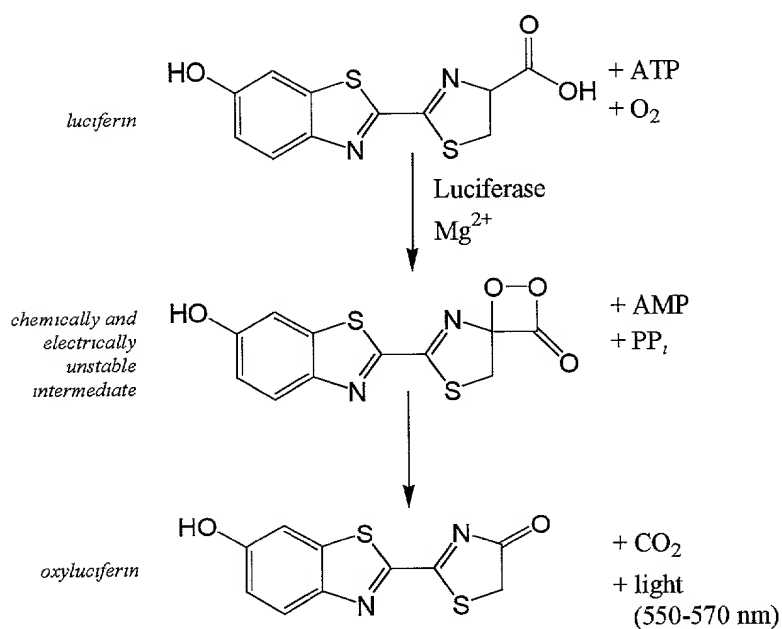
Beetle luciferases, particularly firefly luciferase from the North American firefly *Photinus pyralis*, are well known in the art. The *P. pyralis* luciferase (LucPpy) consists of approximately 550 amino acids of M_r 61 kDa as calculated by the protein encoded by the nucleotide sequence of the gene. However, other firefly luciferases are desirable, such as *Photuris pennsylvanica* firefly luciferase (LucPpe2; 545 amino acid residues; GenBank 2190534, (Ye et al., 1997)). Mutant luciferases derived from LucPpe2 (e.g., LucPpe2m78 (also known as 78-0B10), SEQ ID NO:1; LucPpe2m90 (also known as 90-1B5), SEQ ID NO:2; LucPpe2m133 (also known as 133-1B2), SEQ ID NO:3; LucPpe2m146 (also known as 146-1H2), SEQ ID NO:4 are preferred; however, any luciferase that meets the limitations set forth herein may be used in the composition, method and kits of the invention. The method of making LucPpe2m78, LucPpe2m90, LucPpe2m133, and LucPpe2m146 is disclosed in PCT/US99/30925.

Isolated and/or purified luciferases are typically used in the present invention. Contaminant components of its natural environment are materials that would typically interfere with diagnostic or therapeutic uses for the luciferase, and may include enzymes, hormones, and other proteinaceous or non-proteinaceous materials. One technique to ascertain purity is applying SDS-PAGE analysis under non-reducing or reducing conditions using Coomassie blue or silver stain. Isolated luciferase includes luciferase *in situ* within recombinant cells, since at least one component of the luciferase natural environment will not be present. Luciferases can be isolated from biological specimens that produce luciferase or from a cell that expresses an exogenous polynucleotide encoding a desired luciferase (e.g., a nucleotide encoding 78-0B10, 90-1B5, 133-1B2, or 146-1H2 (SEQ ID NOs: 5-8, respectively)). Such techniques are well known to those of skill in the art.

The naturally-occurring substrate for beetle luciferases is firefly luciferin, a polytherocyclic organic acid, D-(-)-2-(6'-hydroxy-2'-benzothiazolyl)- Δ^2 -thiazolin-4-carboxylic acid (luciferin). Luciferin may be isolated from nature (e.g. from fireflies) or synthesized. Synthetic luciferin can have the same structure as the naturally occurring luciferin or can be derivatized, so long as it functions analogously (Bowie et al., 1973; Branchini, 2000; Craig et al., 1991; Miska and Geiger, 1987; Yang and Thomason, 1993). Examples of derivatives of luciferin include D-luciferin methyl ester, D-luciferyl-L-phenylalanine, D-luciferyl-L-N α -arginine, D-luciferin-O-

sulphate and D-luciferin-O-phosphate (Miska and Geiger, 1987), esters of luciferases that are hydrolyzed or acted upon by esterases to luciferin by components in a sample (Craig et al., 1991; Yang and Thomason, 1993). Other examples of useful luciferin analogs include naphthyl- and quinolyl-luciferin, which emit light in the green and red light spectra respectively (Branchini et al., 1989). There are multiple commercial sources for luciferin (e.g., Promega Corp. Madison, WI; Molecular Probes, Eugene, OR).

The beetle luciferase-catalyzed reaction that yields luminescence (the luciferase-luciferin reaction) involves firefly luciferin, adenosine triphosphate (ATP), magnesium, and molecular oxygen. In the initial reaction, the firefly luciferin and ATP react to form luciferyl adenylate with the elimination of inorganic pyrophosphate. The luciferyl adenylate remains tightly bound to the catalytic site of luciferase. When this form of the enzyme is exposed to molecular oxygen, the enzyme-bound luciferyl adenylate is oxidized to yield oxyluciferin in an electronically excited state. The excited oxidized luciferin emits light on returning to the ground state:



It is contemplated that the ATP function of the reaction can be performed by an ATP analogue (*e.g.*, dATP). It is also contemplated that other ions can serve as substitutes for magnesium ions (*e.g.*, Mn^{2+} or Ca^{2+}). Additionally, oxygen is a reactant of the reaction. Therefore, the reaction should not be conducted under anaerobic conditions. However, it is not generally necessary in practicing the invention to provide oxygen over and above that present in the air. Reactions can take place in closed vessels, provided there is sufficient oxygen in the reaction solution.

Most luciferase-luciferin reactions generate a flash of light that is short lived. However, some of the luciferases preferred for use with the invention, *e.g.*, LucPpe2m146 and LucPpe2m90 luciferases, under the conditions of the invention generate a "glow-type" luminescent signal with less than 50% loss of luminescence per hour after the reagent composition is combined with the sample.

Any luciferase, luciferase variant, luciferase fragment, or variant luciferase fragment that retains the ability to generate luminescence when used in the reagent composition of the present invention and does not prevent the reagent composition from meeting the stability requirements of the present invention, can be used in the present invention.

A full length luciferase variant will have at least about 80% amino acid sequence identity, preferably at least about 81% amino acid sequence identity, more preferably at least about 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98% amino acid sequence identity and most preferably at least about 99% amino acid sequence identity with a full-length native sequence luciferase sequence and retain the ability to generate luminescence.

Ordinarily, variant luciferase fragments are at least about 50 amino acids in length, often at least about 60 amino acids in length, more often at least about 70, 80, 90, 100, 150, 200, 300, 400, 500 or 550 amino acids in length, or more and retain the ability to generate luminescence. A luciferase, luciferase fragment, luciferase variant or variant luciferase fragment may be fused to other non-luciferase amino acid sequences and still be functional in the invention.

Full length beetle luciferase, fragments of beetle luciferase, variants of beetle luciferase, and variant fragments of beetle luciferase enzyme used in the compositions

and methods of the present invention may be purified from a native source or prepared by a number of techniques, including (1) chemical synthesis, (2) enzymatic (protease) digestion of luciferase, and (3) recombinant DNA methods. Chemical synthesis methods are well known in the art, as are methods that employ proteases to cleave specific sites. To produce segments of luciferase protein, segments of *luciferase* or *luciferase* variants can be made and then expressed in a host organism, such as *E. coli*. Methods such as endonuclease digestion or polymerase chain reaction (PCR) allow one of skill in the art to generate an unlimited supply of well-defined fragments. Preferably, luciferase fragments share at least one biological activity with native luciferase, as well as catalytic activity, although the level of activity may vary from that of the native luciferase.

Any type of amino acid substitution, insertion or deletion, or combination thereof may be used to generate a variant luciferase. However, a luciferase with a conservative amino acid substitution is more likely to retain activity. Useful conservative substitutions are shown in Table A "Preferred substitutions." Conservative substitutions whereby an amino acid of one class is replaced with another amino acid of the same type fall within the scope of the invention if the substitution does not impair luciferase activity.

Table A. Preferred substitutions

Original residue	Exemplary substitutions	Preferred substitution
Ala (A)	Val, Leu, Ile	Val
Arg (R)	Lys, Gln, Asn	Lys
Asn (N)	Gln, His, Lys, Arg	Gln
Asp (D)	Glu	Glu
Cys (C)	Ser	Ser
Gln (Q)	Asn	Asn
Glu (E)	Asp	Asp
Gly (G)	Pro, Ala	Ala
His (H)	Asn, Gln, Lys, Arg	Arg
Ile (I)	eu, Val, Met, Ala, Phe, Norleucine	Leu
Leu (L)	Norleucine, Ile, Val, Met, Ala, Phe	Ile
Lys (K)	Arg, Gln, Asn	Arg
Met (M)	Leu, Phe, Ile	Leu
Phe (F)	Leu, Val, Ile, Ala, Tyr	Leu
Pro (P)	Ala	Ala
Ser (S)	Thr	Thr
Thr (T)	Ser	Ser
Trp (W)	Tyr, Phe	Tyr
Tyr (Y)	Trp, Phe, Thr, Ser	Phe
Val (V)	Ile, Leu, Met, Phe, Ala, Norleucine	Leu

Non-conservative substitutions that effect (1) the structure of the polypeptide backbone, such as a β -sheet or α -helical conformation, (2) the charge or (3) hydrophobicity, or (4) the bulk of the side chain of the target site might modify luciferase function. Residues are divided into groups based on common side-chain properties as denoted in Table B. Non-conservative substitutions entail exchanging a member of one of these classes for another class.

Table B. Amino acid classes

Class	Amino acids
Hydrophobic	Norleucine, Met, Ala, Val, Leu, Ile
neutral hydrophilic	Cys, Ser, Thr
Acidic	Asp, Glu
Basic	Asn, Gln, His, Lys, Arg
disrupt chain conformation	Gly, Pro
Aromatic	Trp, Tyr, Phe

Variant *luciferase* genes or gene fragments can be made using methods known in the art such as oligonucleotide-mediated (site-directed) mutagenesis, alanine

scanning, and PCR mutagenesis. Site-directed mutagenesis (Carter, 1986; Zoller and Smith, 1987), cassette mutagenesis, restriction selection mutagenesis (Wells et al., 1985) or other known techniques can be performed on the cloned DNA to produce the luciferase variant DNA (Ausubel et al., 1987; Sambrook, 1989).

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2. Preferred luciferases

Preferred luciferases of the invention possess catalytic activity that depends on ATP and emits photons. Preferred luciferases of the invention have enhanced chemostability in the presence of ATPase inhibitors relative to the level of the *P. pyralis* luciferase (LucPpy) chemostability in the same reaction conditions. Preferred luciferases used in the compositions and methods of the invention generate a stable signal, *i.e.*, they yield enhanced duration of luminescence in a luciferase reaction defined as less than 50% loss of luminescence per hour relative to the luminescence at the time the luciferase reaction was initiated. Preferred luciferases of the invention allow for multiple analyses of a sample over time or analysis of many samples over time, one hour after the luciferase is combined with the ATPase inhibitor, more preferably two hours and most preferably four hours or more. Optionally, the luciferases used in the compositions and methods of the invention have enhanced thermostability properties. An exemplified preferred luciferase is LucPpe2m146 (SEQ ID NO:4). Additional examples of enzymes useful in the invention include, but are not limited to, LucPpe2m78 (SEQ ID NO:1), LucPpe2m90 (SEQ ID NO:2), and LucPpe2m133 (SEQ ID NO:3).

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The exemplified luciferases, LucPpe2m78 (SEQ ID NO:1), LucPpe2m90 (SEQ ID NO:2), LucPpe2m133 (SEQ ID NO:3) and LucPpe2m146 (SEQ ID NO:4) were generated from a mutant of *P. pennsylvanica* (T249M). The nucleic acid sequence encoding this protein was subjected to mutagenic methods including recursive mutagenesis followed by screens for thermostability, signal stability, and substrate binding and is fully described by Wood and Hall (WO 9914336, 1999).

30

Chemostability

“Chemostable luciferases” as used herein, defines luciferases that retain activity in the presence of compounds or conditions when those compounds or

conditions typically inhibit ATPases and disrupt the function of non-chemostable luciferases such as LucPpy. The above identified exemplary luciferases [(LucPpe2m78 (SEQ ID NO:1), LucPpe2m90 (SEQ ID NO:2), LucPpe2m133 (SEQ ID NO:3) and LucPpe2m146 (SEQ ID NO:4)] were found herein to have enhanced chemostability to ATPase inhibitors.

Thus, preferred luciferases include those which maintain at least about 30% (preferably at least about 60%, 70%, 80%, 90%, 95%, 99%) enzymatic activity as measured by luminescence at least one hour (preferably at least two hours, more preferably at least four hours) after contact with an amount of ATPase inhibitor, preferably a detergent, *e.g.*, cationic detergent (preferably DTAB or BDDABr), anionic detergent (preferably deoxycholate or SDS) or zwitterionic detergent (preferably sulfobetaine 3-10) or combination thereof sufficient to collectively reduce ATPase activity endogenous to a sample by at least about 25% (preferably at least about 30%, even more preferably at least about 40%, 50%, 60%, 70%, 80%, 90%, 95%, 99% or any increment therein) relative to the sample's ATPase activity in the absence of the ATPase inhibitor.

The chemostability of an enzyme also may be indicated by the rate of decline of its activity over time. For example, shortly (0 to 10 minutes) after mixing the ATPase inhibitor and the luciferase, thereby creating the reagent composition, at several subsequent timepoints an aliquot of the reagent composition is added to a sample and relative light unit (rlu) measurements are obtained shortly thereafter. These measurements may be graphed to determine a trend of decline in enzyme activity in the reagent composition over time.

The preferred chemostable luciferases (*e.g.*, Ppe2m78, Ppe2m90, Ppe2m133, and Ppe2m146) also retain activity in multi-detergent solutions. Specifically, solutions containing 0.01%, preferably 0.05%, 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6%, 0.7%, 0.8%, 0.9%, most preferably 0.25% CHAPS (3-([3-Cholamidopropyl]dimethylammonio)-1-propanesulfonate) with at least 0.01%, preferably 0.05%, 0.1%, 0.2%, and most preferably 0.3% or 1.0% BDDABr, taurocholic or tauroolithocholic acids, or DTAB, or 0.01%, preferably 0.05%, 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6%, 0.7%, 0.8%, 0.9%, most preferably 1.0% of taurocholic or tauroolithocholic acids with at least 0.01%, preferably 0.05%, 0.1%,

0.2%, and most preferably 0.3% or 1.0% BDDABr, DTAB, or CHAPS. Other multi-detergent solutions in which LucPpe2m78, LucPpe2m90, LucPpe2m133 and LucPpe2m146 retain activity include 0.01%, preferably 0.05%, most preferably 0.1% TRITON X-100 with at least 0.01%, preferably 0.05%, 0.1%, 0.2%, 0.5%, most preferably 1.0% BDDABr, DTAB, or CHAPS; or 0.01%, preferably 0.05%, 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6%, 0.7%, 0.8%, 0.9%, most preferably 1.0% of taurocholic or tauro lithocholic acids with at least 0.01%, preferably 0.05%, 0.1%, 0.2% and most preferably 0.3 or 1.0% BDDABr, DTAB, or CHAPS; or 0.05%, 1.0%, 2.0%, 4.0%, preferably 2% polyethylene glycol 400 dodecyl ether (THESIT), with at least 0.05%, preferably 0.1%, 0.2% and most preferably 0.3% or 1.0% BDDABr, DTAB, or CHAPS .

Thermostability

In some embodiments, a thermostable luciferase that produces luminescence or other thermostable ATP-dependent enzyme that produces a detectable signal is desirable, especially in samples that are treated with heat immediately prior to ATP detection. A thermostable polypeptide remains active at temperatures that inactivate or denature other proteins. The LucPpe2m78, LucPpe2m90, LucPpe2m133 and LucPpe2m146 enzymes display increased thermostability compared to luciferases found in nature or encoded from polynucleotides isolated from nature.

Signal stability

Preferred luciferases used in the compositions and methods of the invention generate a stable signal, *i.e.*, such luciferases, when used in a luciferase reaction, yield luminescence with enhanced duration defined as less than 50% loss of luminescence per hour relative to the luminescence at the time the luciferase reaction was initiated. This property is referred to as signal stability. Preferred luciferases of the invention allow for multiple analyses of a sample over time or analysis of many samples over time, at least one hour after the luciferase is combined with the ATPase inhibitor, more preferably at least two hours and most preferably at least four hours or more. The combination of a luciferase and an ATPase inhibitor in the reagent composition, wherein the luciferase is capable of producing luminescence with enhanced duration

while in the presence of an ATPase inhibitor (and, optionally, kinase inhibitors) that stabilizes the amount of ATP present in the sample results in a reliable and efficient method for detecting and quantifying cellular ATP for extended periods of time.

5 3. Other desirable luciferases

Any luciferase, luciferase fragment, or variants thereof that, in an ATP-dependent manner, emits photons upon oxidation of a substrate and is chemostable, *i.e.*, retains activity in the presence of the ATPase inhibitors of the invention, may be used in the present invention. Other desirable characteristics, although not obligatory,
10 such as thermostability and signal stability, are contemplated. In addition, the luciferase may be fused to another amino acid sequence and still be functional in the present invention. Such enzymes may be synthesized *in vitro* or isolated from other organisms.

Other luciferases are found in bacteria, unicellular algae, coelenterates, beetles
15 (other than *P. pennsylvanica*), fishes, and other organisms. Chemically, all luciferases involve exergonic reactions of molecular oxygen with different luciferins, resulting in photon production (Hastings, 1996; Hastings and Wilson, 1976; Wilson and Hastings, 1998; Wood et al., 1989). Preferably, other luciferases should be dependent on ATP for oxidation of luciferin, or the reaction conditions manipulated such that
20 bioluminescence generation depends on ATP. One of skill in the art can ascertain ATP dependence for the luciferase-luciferin reaction.

The use of a luciferase other than that from beetles requires an appropriate luciferin molecule that upon oxidation generates a chemically and electrically unstable intermediate or a detectable enzymatic product. Other substrates may be
25 used, as well as other ATP-dependent enzymes that produce a detectable enzymatic product. Detectable products include photons, radioactively-labeled products, insoluble or soluble chromogens, or other products that can be detected visually or through the use of devices.

30 C. Kits

When the invention is supplied as a kit, the different components of the composition may be packaged in separate containers and admixed prior to use. Such

separate packaging of the components permits long-term storage without loss of luciferase-luciferin activity. However, when the various parts of the kit are admixed, thereby forming the “reagent composition”, the reagent composition comprises a luciferase, such as exemplified by, but not limited to, SEQ ID NOs:1-4, and one or more ATPase inhibitors wherein the activity of the reagent composition has enhanced stability [*i.e.*, the reagent composition is capable of maintaining at least about 30%, more preferably at least about 60% activity for at least one hour, even more preferably at least 70%, 80%, 90%, 95%, 99% or greater activity for at least one hour, still more preferably for at least two hours and even more preferably for at least four hours (as measured by luminescence when the reagent composition is combined with a sample) relative to the reagent composition's activity when it is first created, *i.e.*, 0 to 10 minutes after the luciferase enzyme is first combined with an ATPase inhibitor], and wherein the ATPase inhibitor is present in the reagent composition at a concentration sufficient to reduce ATPase activity endogenous to a sample by at least about 25%, more preferably at least about 30%, even more preferably at least about 40%, 50%, 60%, 70%, 80%, 90%, 95%, or 99% or greater relative to the ATPase activity in the absence of the ATPase inhibitor. Instructional materials may also be enclosed in the kit, as well as materials that may act as standards or controls, depending on the purpose of the kit.

1. The reagent composition

In a preferred embodiment, the components of the reagent composition of the invention can be supplied as two parts that are admixed shortly before use: (1) a part comprising luciferase and (2) a part comprising one or more ATPase inhibitors. An example of such an embodiment is represented in Table C and others are represented in the Examples. The luciferase component may further comprise luciferin and preferably is lyophilized. The luciferase component optionally comprises excipients for lyophilization, protein (luciferase) stabilizer, magnesium (or alternative cation), and a magnesium chelator (or alternative cation chelator). The ATPase inhibitor component may further comprise a buffer, divalent cation metal chelators, magnesium (or alternative cation), a defoaming agent, anti-ATP-generating enzyme agents (*e.g.*, NaF), an enzyme stabilizer (*e.g.*, THESIT) and cell lysing agent or agent for

extracting ATP from cells. The different components of the invention may comprise subsets of these parts and may be combined in any way that either facilitates the application of the invention or prolongs storage life.

Table C. Preferred components of a kit

Component	Action	Preferred embodiments
luciferase\ luciferin	Catalyzes luciferase-luciferin reaction in one step	Ppe2m90 or Ppe2m146 luciferase
	Substrate	Luciferin
	Lyophilization excipient and protein stabilizer	Highly purified porcine dermal collagen (Prionex)
	Enzyme cofactor	MgSO ₄
	Chelates Mg after ATP removal	1,2-Cyclohexanediaminetetraacetic acid (CDTA)
ATPase/ Extraction	Buffer	Citrate buffer Potassium Phosphate buffer
	Buffer	2-(N-Morpholino)ethanesulfonic acid (MES)
	Chelates divalent metal cations	Ethylenediaminetetraacetic (EDTA)
	Defoamer	MAZU DF204
	ATPase inhibitor	DTAB
	Inhibitor of ATP-generating activity	NaF
	Non-ionic detergent, disrupts cellular membranes	THESIT, Polyoxyethylene(9)-lauryl-ether

2. Luciferase-luciferin component

All luciferases, luciferase variants, luciferase fragments and variant luciferase fragments that catalyze an ATP-dependent reaction and generate luminescence are

contemplated for use in the invention. Some embodiments eliminate the luciferin; for example, allowing a user to supply a luciferin of his/her choice, or the luciferin may be provided separately. The type of luciferin provided may vary but it must be a substrate for the type of luciferase provided.

5 In one embodiment, a kit supplies the luciferase as an anhydrous preparation. Anhydrous preparations of luciferase may be lyophilized, in which water is removed under vacuum, freeze-dried, crystallized, or any other method that removes water that does not inactivate luciferase. Excipients that bulk the preparation and stabilize luciferase, such as serum albumins or Prionex, may also be included. In other
10 embodiments, luciferase may be suspended in an aqueous composition comprising glycerol or other solvent in which the enzyme is stable. The skilled artisan can easily determine the amounts of the various constituents that work in the compositions and methods of the invention.

15 3. ATPase inhibitor component

 In a preferred embodiment, the kit comprises a component containing one or more ATPase inhibitors within a solution optionally containing other functional components, such as buffers, defoamers, enzyme stabilizers, and the like. This component may be supplied as a working solution or as a concentrate. A cell lysing
20 agent or an agent that allows for cellular ATP extraction (*e.g.*, CTAB) may be packaged separately or together with the ATPase inhibitor component. The ATPase inhibitor may be any of those described herein above. This component may further comprise agents that chelate metal ions that may interfere with the luciferase-luciferin reaction (*e.g.* EDTA, EGTA), magnesium (preferably supplied as a salt, such as
25 sulfate or chloride; or other functionally equivalent cation), defoaming agents, and inhibitors of ATP generating enzyme (*e.g.* NaF). Buffers that maintain pH of the working solution, *e.g.* citrate or MES (which may be supplied as a salt, such as sodium or free acid or base) or any other appropriate buffer may be used.

30 *ATPase inhibitor*

 One aspect of the invention is an ATPase inhibitor, preferably a detergent that inhibits ATPases, more preferably a detergent with a charged group, *e.g.*, cationic

detergent (preferably DTAB or BDDABr), anionic detergent (preferably deoxycholate or SDS) or zwitterionic detergent (preferably sulfobetaine 3-10). Such inhibitors prevent ATPases endogenous to the sample from processing ATP to adenosine diphosphate (ADP) and adenosine monophosphate (AMP) before the luciferase is allowed to utilize the ATP in the sample for the luciferase-luciferin reaction. ATPase inhibitors may inactivate ATPases directly or indirectly. They may bind to ATPases, either in the active sites, thus preventing substrate binding, or denature ATPases, such as by denaturing detergents, or they may selectively sequester ATPases from their substrates.

One embodiment of the present invention uses cationic detergents such as DTAB or BDDABr detergents that act as ATPase inhibitors. However, other ATPase inhibitors are contemplated, such as other cationic detergents, anionic detergents (*e.g.*, SDS and deoxycholate) and zwitterionic detergents (*e.g.*, sulfobetaine 3-10).

For DTAB or BDDABr the concentration in the reagent composition is preferably in the range of about 0.02% to about 5.0%, more preferably about 0.05%, still more preferably about 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6%, 0.7%, 0.8%, 0.9%, 1.0%, 1.1%, 1.2%, 1.3%, 1.4% and 1.5% and most preferably to a final concentration of about 1.0% in the reagent composition.

Other non-cationic detergent ATPase inhibitors are contemplated for inclusion in the reagent composition; their requirements are that they, like DTAB, preferably inhibit at least about 25%, more preferably at least about 30%, 40%, 50%, 60%, 70%, 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, more preferably at least about 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99% and most preferably about 100% of endogenous ATPase activity in a sample when present in a reagent composition wherein the reagent composition is capable of maintaining at least 30%, 40%, 50%, 60%, 70%, 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, more preferably at least about 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99% and most preferably about 100% activity, as measured by luminescence after the reagent composition is combined with the sample, for at least one hour, more preferably at least 2 hours compared to the reagent composition's activity just after the luciferase is combined with the ATPase inhibitor. Potentially suitable non-cationic detergents that function as ATPase inhibitors include anionic detergents

(preferably SDS and deoxycholate), zwitterionic detergents (preferably sulfobetain 3-10). The concentration of a particular ATPase inhibitor will vary depending on the inhibitor used, and to some extent, the sample being analyzed. One of skill in the art is familiar with methods to determine the appropriate concentration of an ATPase inhibitor for inclusion in the reagent composition; for example, they may examine luciferin-luciferase derived signals over time, comparing those samples that have varying concentrations of a candidate ATPase inhibitor to those samples containing no known ATPase inhibitors.

It is fully anticipated that the most preferred concentration and even the concentration range functional in the methods of the invention will vary for different detergents. For example, SDS concentrations functional in the methods of the invention are about 0.002% (Examples 2 and 3). The functional concentration range for a detergent used in the present invention may readily be determined by one of skill in the art using the methods disclosed herein.

It is contemplated that some ATPase inhibitors, at some of the concentrations useful in the invention, may be insoluble or have low solubility in aqueous solutions. These compounds may first be dissolved in an organic solution (*e.g.*, dimethyl sulfoxide or dimethylformamide) and then diluted into the reagent composition for use in the composition and methods of the invention.

Inhibitors of ATP-generating enzymes

In some samples, enzymes such as kinases may be active, allowing for continued production of ATP. Because the ATP concentration is determined at a specific time, if such enzymatic activity is left unchecked, then an over-estimation of the ATP concentration will be made. To counter such ATP-generating activity, inhibitors of ATP production can be used. Although the action of a specific inhibitor may be incompletely understood, their usefulness is not obviated. Examples of useful compounds include NaF, which is useful at concentrations of at least 1 mM, preferably 2 mM to 100 mM or any increment therein; 2 mM is most preferred. Any such inhibitor may be used, however, if it does not adversely affect luciferase so as to take it outside the utility of the invention. One of skill in the art will know how to determine the appropriate concentration of such an inhibitor, whether the inhibitor is

novel or well-known. Other inhibitors of ATP generating enzymes include, but are not limited to, vanadate, paranitrophenylphosphate and dichloroacetic acid (Kiechle et al., 1980).

5

Buffers

Any buffers that maintain suitable pH for the working solution and do not interfere with the luciferase-luciferin reaction are contemplated. The preferred pH range is between about pH 4.5 and about pH 9.0, more preferably between about pH 6.0 and about pH 8.0. In addition to MES and citrate buffers, other buffers, such as phosphate buffered saline (PBS), Tris, N-(2-Hydroxyethyl)piperazine-N'-(2-ethanesulfonic acid) (HEPES), piperazine-1,4-bis(2-ethanesulfonic acid) (PIPES), borate, and any other buffer known to those of skill in the art may be suitable. Selection of appropriate buffers depends on pH buffering capacity and interaction with the luciferase-luciferin reaction.

15

Defoamers

Defoaming agents are desirable to prevent foam from interfering with the detection of bioluminescence, especially in applications that quantify luminescence. Such agents as MAZU may be organic or silicone based. Selection of defoamers depends on their ability to eliminate foam without interfering with the luciferase-luciferin reaction.

20

Magnesium

The beetle luciferase-luciferin reaction is dependent not only on ATP, but also on magnesium ions. To assure luciferase activity, magnesium is exogenously supplied. In addition to magnesium sulfate, other salts of magnesium are contemplated, such as magnesium chloride, magnesium gluconate, magnesium acetate, magnesium bromide, magnesium carbonate, etc. In any case, the magnesium complex must dissociate to make Mg^{2+} ions available to the luciferase and not interfere with the luciferase-luciferin reaction. One of skill in the art is aware that other cations may be functional in place of magnesium. These include calcium and manganese.

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In some applications, endogenous magnesium should be sufficient in which cases exogenous magnesium could be eliminated.

Cell lysing agents and ATP extraction agents

To free any sequestered ATP within a cell and to lyse cells in a sample, cell lysing agents, such as non-ionic detergents, may be included. Any cell lysing agent is contemplated including other non-ionic detergents, (such as from the Triton series) cationic, anionic and zwitterionic detergents, bile salts, chaotropes, and any other agent that disrupts cellular membranes, including bacterial toxins such as oxylysins. Alternatively any agent that allows for ATP extraction from a cell is contemplated (such as CTAB). Agents that allow for ATP extraction from a cell include detergents present at a concentration that puts holes in the cell membrane, allowing for ATP within the cell to leach into the surrounding media, but not present at such a concentration that produces a cell lysate.

Stablizing agents

While resistant to the action of nonionic and low concentrations of zwitterionic detergents (Simpson and Hammond, 1991), native firefly luciferase is inactivated by cationic detergents, such as benzalkonium chloride, benzethonium chloride, CTAB (cetyltrimethylammonium), DTAB (dodecyltrimethylammonium bromide), and methylbenzethonium chloride (Simpson and Hammond, 1991).

The stabilizing agent can be any compound that stabilizes the luciferase from degradation. Suitable stabilizing agents include proteins (such as bovine serum albumin or gelatin) or detergents (preferably non-ionic detergents, most preferably THESIT).

Other agents

Other agents that may be included in a kit include substances that are known to enhance the duration of luminescence resulting from a luciferase reaction, such as co-enzyme A (CoA), thiol reagents, such as dithiothreitol and β mercaptoethanol (Wood, US 5,283,179, 1994; Wood, US 5,650,289, 1997), metal ion chelators such as EDTA to prolong the signal and protease inhibitors (Scheirer, US 5,618,682, 1997;

Scheirer, US 5,866,348, 1999), or high concentrations of salts (Van Lune and Trer Wiel, WO 00/18953, 2000).

Other kit contents

5 Kits may also include reagents in separate containers that facilitate the execution of a specific test, such as cell viability, cytotoxicity, cell proliferation, or determination of ATP concentration. For example, ATP may be supplied so that standard curves may be determined or to be used as internal controls. Substances that are known to be cytotoxic to cells can be included for use as a positive control in tests of cell viability or for the effects of compounds on cells. The kit may supply a sample gathering component such as a membrane, filter or swab.

4. Containers or vessels

15 The reagents included in the kits can be supplied in containers of any sort such that the life of the different components are preserved, and are not adsorbed or altered by the materials of the container. For example, sealed glass ampules may contain lyophilized luciferase or buffer that have been packaged under a neutral, non-reacting gas, such as nitrogen. Ampules may consist of any suitable material, such as glass, organic polymers, such as polycarbonate, polystyrene, *etc.*, ceramic, metal or any other material typically employed to hold reagents. Other examples of suitable containers include simple bottles that may be fabricated from similar substances as ampules, and envelopes, that may consist of foil-lined interiors, such as aluminum or an alloy. Other containers include test tubes, vials, flasks, bottles, syringes, or the like. Containers may have a sterile access port, such as a bottle having a stopper that can be pierced by a hypodermic injection needle. Other containers may have two compartments that are separated by a readily removable membrane that upon removal permits the components to mix. Removable membranes may be glass, plastic, rubber, *etc.*

5. Instructional materials

30 Kits may also be supplied with instructional materials. Instructions may be printed on paper or other substrate, and/or may be supplied as an electronic-readable

medium, such as a floppy disc, CD-ROM, DVD-ROM, Zip disc, videotape, audio tape, *etc.* Detailed instructions may not be physically associated with the kit; instead, a user may be directed to an internet web site specified by the manufacturer or distributor of the kit, or supplied as electronic mail. In a preferred embodiment, the instructions instruct the user to combine the luciferase with the ATPase inhibitor before adding the reagent composition to a sample.

D. Reagent Composition Activity

To measure luminescence and thereby determine the reagent composition activity, the relative light unit (rlu) value generated by the luciferase reaction at a timepoint of interest after the reagent composition is combined with a sample may be measured. For example, an rlu value may be obtained by measuring the resulting luminescence from a sample with a known concentration of ATP combined with the reagent composition just after (0-10 min) the component comprising the ATPase inhibitor is added to the component comprising the luciferase thereby creating the reagent composition. This is considered 100% activity (time zero) under those conditions. If, after combining the component comprising the ATPase inhibitor with the component comprising the luciferase and thereby generating the reagent composition, the reagent composition is left for two hours, preferably in the temperature range of room temperature (about 20°C – about 25°C) to about 37°C, prior to measuring luminescence under identical conditions as the time 0 assay, and the rlu value obtained is greater than 60% of that obtained at time 0, then the reagent composition retained at least 60% of its activity for two hours.

A reagent composition of the present invention retains 30%, 40%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99% or any increment therein and most preferably 100% of its activity, as measured by luminescence after the reagent composition is combined with the sample for at least one hour, preferably for at least two hours, relative to its activity when formulated (time zero)-- that is from the time the component comprising the ATPase inhibitor was added to the component comprising luciferase or shortly thereafter (0 – 10 minutes).

In one preferred embodiment, the working stock of the reagent composition comprises DTAB or BDDBr in concentrations of about 0.02% (preferably about

0.05%, 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6%, 0.7%, 0.8%, 0.9%, 1%, 1.1%, 1.2%, 1.3%, 1.4%, 1.5%, 1.6%, 1.7%, 1.8%, 1.9%, 2%, 2.5%, 3%, 3.5%, 4%, 4.5%, 5%, 5.5%, 6%, 6.5%, 7%, 7.5%, 8%, 8.5%, 9%, 9.5%, 10% and any increment therein, more preferably about 1%) and retains at least about 30% (preferably at least about 40%, 50%, 60%, 70%, 80%, 90%, 95%, 99%) of activity at least one hour (preferably at least two hours) after formulation.

In another preferred embodiment, the reagent compositions comprise sulfobetaine at a concentration of 0.6%, 0.7%, 0.8%, 0.9% or 1.0% or any increment therein, SDS at a concentration of 0.001%, 0.002%, 0.003%, 0.004% or 0.005% or any increment therein, or deoxycholate at a concentration of 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6% or any increment therein and retain at least about 30% (preferably at least about 40%, 50%, 60%, 70%, 80%, 90%, 95%, 99%) of activity at least one hour (preferably at least two hours) after formulation.

E. Detecting and quantifying the products of the luciferase-luciferin reaction

A beetle luciferase-luciferin reaction results in the generation of light ("luminescence"). The invention provides assays for ATP measurement by measuring luminescence. Users may simply visually inspect sample reactions to ascertain the production of light. However, more sensitive instrumentations allow not only detection of faint signals, but also quantification of the light signal. Also contemplated are reactions in which non-light products are measured, according to the nature of the products. Any assay for measurement of ATP that results in a signal may benefit from the present invention. Appropriate instruments and methods for such products will be apparent to the skilled artisan.

In all cases in which light is detected, specialized instruments, such as luminometers, can read the light product of a luciferase-luciferin reaction. Any instrument that can detect light of the wavelengths emitted by the luciferase-luciferin reaction may be used. Such instruments may read samples singularly, or in high-throughput screens, may read many samples housed in the wells of a microwell plates (6, 24, 48, 96, 384, 1536 and so on, well formats). Clearly, the devices used to measure the emitted light do not limit the invention. Other devices that can be used include scintillation counters (Nguyen et al., 1988) or instruments invented or adapted

to be sensitive to luminescence, such as photometers (Picciolo et al., 1977).
Photographic film or X-ray film may also be used to detect luminescence. In
addition, a user may visually inspect a sample to qualitatively evaluate luminescence.

5 F. Uses for ATP-dependent luciferase-luciferin reactions

Because the beetle luciferase-luciferin reaction is ATP-dependent, luciferase
can be used to assay for ATP. The reaction is remarkably sensitive, allowing ATP to
be detected in a sample containing as little as 10^{-16} moles ATP or less. This
sensitivity can be exploited to understand cell viability and the effects that exogenous
10 substances may exert on cell metabolism and viability. In a cellular context, ATP
powers cellular metabolism, the presence of ATP correlates to an actively
metabolizing cell, the cell is “viable”.

The invention is drawn to methods, compositions and kits that are used to
effectively and accurately detect and quantify cellular ATP levels, exploiting the
15 ATP-dependence of beetle luciferase to oxidize luciferin.

The invention comprises the addition of a single composition (reagent
composition) that comprises a luciferase and at least one ATPase inhibitor to a sample
and then detecting luminescence. Optionally, a kinase inhibitor or a compound that
prevents accumulation of ATP can also be present in the reagent composition.
20 Additionally, a cell-lysing agent (*e.g.*, a polyoxyethylene such as THESIT) or an ATP
extracting agent may be present in the composition. This single step comprising
adding the reagent composition followed by reading the luminescence represents a
significant advance in assays for ATP.

25 1. Detecting ATP

The methods, compositions and kits of the invention provide for the simple
qualitative or quantitative detection of ATP (or ATP analogue which can function as a
luciferase substrate) in a sample. In preferred embodiments, a simple qualitative
experiment in which luminescence is generated in a sample using the invention,
30 indicates the presence of ATP. Luminescence is generated using a reagent
composition comprising luciferase such as LucPpe2m78, LucPpe2m90,
LucPpe2m133 or LucPpe2m146, and one or more ATPase inhibitors. In addition, the

reagent composition may further comprise one or more of the following components: luciferin, which may be reconstituted from a lyophilized preparation, (alternatively, an appropriate luciferin-analogue substrate), ATPase inhibitor(s), inhibitor(s) of ATP-generating enzymes such as kinases, divalent cation (*e.g.* magnesium), enzyme stabilizing agent, buffer, cell-lysis agent, cellular ATP extracting agent.

A sample may be anything that is suspected of containing ATP or ATP analogue, such as cell lysates, intact cells, biopsies, foods, beverages, swabs wiped on surfaces such as those of animals, plants, or inanimate objects, and the like. Other examples of samples include compositions of a known ATP concentration. Cells or cell lysates may be from any organism, prokaryotic or eukaryotic. Examples of prokaryotic cells include *E. coli*, *P. aeruginosa*, *B. subtilis*, and *S. typhimurium*. Eukaryotic cells may be from plants, animals, fungi, insects, *etc.* or cultured cells from such organisms. Examples include *A. thaliana* and *Brassica sp.*, *Chlamydomonas sp.* and *Volvox sp.* (plants), *H. sapiens* and *Mus sp.* (animals), *Saccharomyces sp.* (*esp. cerevisiae* and *pombe*) and *Neurospora sp.* (fungi), *D. melanogaster* and *C. elegans* (insects), *in vitro* cultured callus cells from any plant, primary cells cultured *in vitro* from any organism (such as organ explants from, for example, rodents), mammalian cell lines such as Madin-Darby canine kidney (MDCK) and Chinese hamster ovary (CHO) cells, and insect cell lines such as Z cells. These examples are furnished only as examples and are not meant to be limiting.

A cell lysate comprises cellular components that are no longer organized into a recognizable intact cellular architecture. Cell lysates may have soluble and insoluble components, either of which may be removed before using the lysate. Lysates may be prepared by any means, including physical disruption using sonication, a dounce, mortar and pestle, freeze-thaw cycling, or any other device or process that destroys the physical integrity of cells; or lysis by detergents, such as those in which LucPpe2m146 retains activity, such as zwitterionic and nonionic detergents, or cationic detergents DTAB or CTAB. Preferably, the cell lysate is produced in such a way that the integrity of the ATP concentration is preserved at the time the cells are harvested. To accurately detect ATP in a sample, enzymes that would degrade cellular ATP or those that would generate ATP are preferably inhibited. In the absence of such inhibitors, an inaccurate determination of ATP concentration risks

being made. Inhibitors such as DTAB inactivate ATPases, while other molecules such as NaF inactivate ATP-generating enzyme activity. It is hypothesized, yet not fully understood, that for those cell types in which NaF is effective (*e.g.*, lymphoid cells), NaF is potentially acting to inhibit (a) kinase(s).

5 Inhibitors of ATP-generating enzymes, those enzymes that have as a product or by-product ATP, such as the activity of kinases, may be incorporated into the reagent composition. An example of an effective inhibitor is NaF (Bostick et al., 1982). Such compositions comprise NaF at concentrations of at least 0.5mM, preferably at least 1 mM, more preferably at least 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 10 14, 15, 16, 17, 18, 19, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100 mM or any increment therein; 2 mM is most preferred. Other inhibitors of ATP-generating enzymes include other kinase inhibitors, such as vanadate, AMP, DAPP (Bostick et al., 1982) and dichloroacetic acid (Kiechle et al., 15 1980).

2. Quantifying ATP

The compositions, methods and kits of the invention permit a user to quantify the amount of ATP in a sample by quantifying the amount of luminescence. The invention is applied to a sample of interest, and also to samples containing known amounts of ATP (controls). The signal generated from applying the invention to a sample of unknown ATP concentration is correlated to signals generated either by internal controls (the addition of a known amount of ATP to a sample and measuring the subsequent luminescence) or external standard curves, generated by measuring the luminescence of several samples of known ATP concentrations and plotting them graphically. Such methods are known to skilled artisans. (Moyer and Henderson, 20 1983; Ronner et al., 1999; Stanley, 1989; Wood et al., 1989).

3. Cell viability

30 The presence of ATP in a cell, eukaryotic or prokaryotic, indicates active metabolic processes, indicating a viable cell. The compositions, methods and kits of the present invention can be used to assay cell viability (Cree, 1998; Jassim et al.,

1990; Petty et al., 1995). An accurate measure of cell viability allows for the accurate assessment of the effects of substances on cells; other purposes for determining cell viability are well-known to those of skill in the art.

Determining cell viability is useful, for example, to determine cytotoxicity, cell proliferation, biological phenomena, necrosis, or alterations in cellular metabolism. Cell viability assays can also determine the overall viability of a cell population.

The sample in which ATP is measured to determine cell viability may be viable cells themselves, a cell lysate or any other sample suspected of containing cells. When using cells, modified beetle luciferases that are membrane permeable may be used (for example, see (Craig et al., 1991)). In many cases, however, a cell lysate is preferred.

4. Effects of compounds on cells

The compositions, methods and kits of the present invention can be applied to measure the effects of compounds, such as inorganics, small organics, peptides, proteins and polypeptides, on cellular metabolism when contacted with a sample (Aiginger et al., 1980; Andreotti et al., 1995; Bradbury et al., 2000; Cree and Andreotti, 1997; Crouch et al., 1993; Kangas et al., 1984). Determining the effects of compounds on cells can assess the measure of a potential pharmaceutical composition's effectiveness. Cytotoxic compounds—those that kill cells—can be useful in the treatment of cancer cells, especially if they selectively kill quickly-dividing cells. In other cases, a compound with some other usefulness may be negated if a cytotoxic effect is not desired. Because ATP is a measure of a cell's "metabolic" health, an abnormal surge or depression of ATP reduction indicates a change in cellular homeostasis. Compounds that contact cells can influence ATP production through a large number of mechanisms, most notably cell death and cell proliferation. These compounds may be catalogued in compound libraries, or tested singly. Such applications of the invention apply controls in which samples are contacted with control substances whose effects on ATP metabolism are known. Also preferably, controls include samples in which luciferase and the compound are present together to assure that the compound itself is not directly affecting luciferase activity.

The following examples are intended to illustrate the present invention without limitation.

5

EXAMPLES

Example 1 I. Detergents that Inhibit ATPases

10 This example was designed to test the ability of different detergents to inhibit ATPase activity endogenous to cells and demonstrate the level of such inhibition. Three separate detergents in each of four detergent classes were tested: anionic [SDS (Sodium dodecyl sulfate), Bioterge (an α olefin sulfate), and sodium deoxycholate], nonionic [TRITON X-100, BigCHAP (N,N-bis(3-D-Gluconamidopropyl)cholamide) and THESIT (polyethylene glycol 400 dodecyl ether, Fluka, #88315)], cationic 15 [BDDABr (Benzyltrimethylammonium bromide), CTAB (Cetyltrimethylammonium bromide), and DTAB (dodecyltrimethylammonium bromide)] and zwitterionic [CHAPS (3-[(3-Cholamidopropyl)dimethylammonio]propanesulfonic acid), CHAPSO (3-[(3-Cholamidopropyl)dimethylammonio]-2-hydroxy-1-propanesulfonate), and Sulfobetaine 3-10 (N-Dodecyl-N,N-dimethyl-3-ammonio-1-propanesulfonate)]. Detergents were obtained from Sigma, Fluka and Aldrich. 20

L929 cells (ATCC CCL-1; 1.5×10^5 cells/ml) in F12/DMEM (Hyclone, SH30023) containing 10% horse serum (Hyclone, SH30074) were frozen and thawed for four cycles to create a cell lysate. Then 50 μ l of stock detergent solutions [10%, 5.0%, 1.0%, and 0.5% (w/v)] were separately added to 450 μ l cell lysate, creating a 25 final detergent concentration in the cell lysate sample of 1.0%, 0.5%, 0.1%, and 0.05%, respectively (these percentage values are those used in Tables D and E herein below). Control samples contained either lysate only or 1.0 μ M ATP in 15 mM HEPES buffer (pH 7.5). All samples were incubated at 22°C (room temperature) for 30 the duration of the experiment.

At various timepoints, 20 µl from each sample/detergent mixture was added to a 96-well luminometer plate in triplicate, and then 100 µl of a solution ("luciferase-luciferin" or "L/L reagent") containing 25 mM HEPES buffer (pH 7.5), 40 µg luciferase enzyme LucPpe2m146 (Promega, E140), 100 µM luciferin (Promega), and 10 mM MgSO₄ was added to each well. The L/L reagent was stored at 4°C for the duration of the experiment and then allowed to reach ambient temperature just before assaying. After mixing the contents of the plate, light output was measured with a Dynex MLX microtiter plate luminometer (Chantilly, VA), 0.5 second reads per well with the first measurement taken five minutes after the detergent solution was combined with the sample. The average relative light units and the timepoint at which it was measured (rlu; Table D) and percent of remaining luciferase activity at the timepoint (Table E) are reported; controls were run with each set of experimental conditions as indicated. The cationic and anionic detergents were assayed on one day with one set of controls. The zwitterionic and nonionic detergents were assayed on a separate day with a separate set of controls. The DTAB at 0.5% was assayed on both days (1 and 2). If the original average rlu reported in Table D were below 5.0, the percent of original activity values were not recorded in Table E as the detergent was determined to be present at a concentration that significantly destroyed luciferase activity.

Table D **Average Relative Light Unit Values**

	5 min	75 min	169 min	222 min	260 min
Controls					
Cell lysate (cationic and anionic)	6713.33	1844.71	953.35	384.77	200.78
Cell lysate (nonionic and zwitterionic)	6748.77	2297.65	1212.43	508.38	246.19
ATP Control (cationic and anionic)	19986.2	16628.6	17439.9	20174.3	15668.7
ATP Control (nonionic and zwitterionic)	17779.6	18218.8	16639.6	18886.2	17952.2

	5 min	75 min	169 min	222 min	260 min
Anionic Detergents					
SDS					
1.0%	0.01	0.00	0.01	0.00	0.01
0.5%	0.00	0.00	0.02	0.00	0.00
0.1%	0.31	0.18	0.21	0.26	0.34
0.05%	1181.17	1060.03	949.7	921.86	803.0
Bioterge					
1.0%	0.01	0.01	0.01	0.01	0.02
0.5%	0.1	0.04	0.05	0.05	0.05
0.1%	4788.81	1445.91	167.09	96.43	64.83
0.05%	5343.62	1004.34	435.52	196.51	107.54
Deoxycholate					
1.0%	3.98	3.63	3.63	3.15	3.24
0.5%	3189.56	2715.45	2268.77	2105.38	1845.36
0.1%	6422.34	3730.44	1627.81	1028.42	669.31
0.05%	5810.85	1729.95	738.1	375.74	188.59
Non-ionic Detergents					
TRITON X-100					
1.0%	6073.78	1774.10	839.14	331.95	174.89
0.5%	6106.61	1880.98	871.01	378.58	195.42
0.1%	6837.20	3004.57	1643.05	801.38	448.93
0.05%	6160.71	1964.17	822.48	303.73	147.48
BIGCHAP					
1.0%	7576.05	4043.35	2474.59	1374.29	822.65
0.5%	7438.53	3618.22	2092.69	1144.80	677.61
0.1%	6607.01	2087.01	1363.07	634.92	301.55
0.05%	6410.42	2260.45	1036.69	487.72	238.44
THESIT					
1.0%	6204.02	1979.43	968.14	416.45	210.78
0.5%	6392.75	2304.48	1122.24	487.28	240.72
0.1%	6022.32	2654.97	1509.07	755.94	447.44
0.05%	5632.96	1601.09	623.38	211.67	110.15
Cationic Detergents					
BDDABr					

	5 min	75 min	169 min	222 min	260 min
1.0%	0.49	0.51	0.44	0.42	0.43
0.5%	122.47	107.39	93.92	96.68	101.11
0.1%	7069.08	5136.92	3260.59	2366.49	1767.58
0.05%	7077.46	4539.97	2465.57	1680.16	1233.82
CTAB					
1.0%	0.09	0.08	0.07	0.06	0.07
0.5%	0.34	0.28	0.23	0.27	0.18
0.1%	5104.82	3607.65	1889.29	1248.51	not done
0.05%	6525.51	4029.32	2093.80	1437.67	1002.72
DTAB					
1.0%	800.61	693.13	649.41	671.03	645.40
0.5% (day1)	5630.61	5100.09	4957.48	4916.46	4515.20
0.5% (day2)	6617.08	6341.09	5977.33	5824.18	5622.12
0.1%	6991.01	4753.46	2737.36	1950.95	1408.18
0.05%	6487.93	3138.81	1496.01	943.40	638.30
Zwitterionic Detergents					
CHAPS					
1.0%	7241.33	3816.06	2348.28	1322.30	809.22
0.5%	7368.91	4048.24	2548.39	1438.57	909.15
0.1%	6515.77	2583.65	1236.53	448.96	284.18
0.05%	6356.62	2305.56	1143.02	500.80	240.81
CHAPSO					
1.0%	7160.63	3803.84	2376.31	1332.97	840.57
0.5%	7422.26	4089.32	2581.01	1460.54	923.81
0.1%	6549.85	2584.56	1210.14	558.69	280.84
0.05%	6396.53	2424.54	1124.83	480.09	238.80
Sulfobetaine 3-10					
1.0%	7861.36	5703.51	4318.46	3075.12	2193.02
0.5%	6565.98	2405.95	1211.13	609.75	391.64
0.1%	6506.61	2367.27	1100.37	446.29	222.22
0.05%	6247.31	2270.13	1053.56	465.03	233.19

Table E Percent ATP Remaining

Condition	5 min	75 min	169 min	222 min	260 min
Cell lysate (cationic)	100	27.5	14.2	5.7	3.0

Condition	5 min	75 min	169 min	222 min	260 min
and anionic)					
Cell lysate (nonionic and zwitterionic)	100	34.0	18.0	7.5	3.6
ATP Control (cationic and anionic)	100	83.2	87.3	100.9	78.4
ATP Control (nonionic and zwitterionic)	100	102.5	93.6	106.2	101.0
Anionic Detergents					
SDS					
0.05%	100	89.7	80.4	78.0	68.0
Bioteerge					
0.1%	100	30.2	3.5	2.0	1.4
0.05%	100	18.8	8.2	3.7	2.0
Deoxycholate					
0.5%	100	85.1	71.1	66.0	57.9
0.1%	100	57.9	25.3	16.0	10.4
0.05%	100	29.8	12.7	6.5	3.2
Non-ionic Detergents					
TRITON X-100					
1.0%	100	29.2	13.8	5.5	2.9
0.5%	100	30.8	14.3	6.2	3.2
0.1%	100	43.9	24.0	11.7	6.6
0.05%	100	31.9	13.4	4.9	2.4
BIGCHAP					
1.0%	100	53.4	32.7	18.1	10.9
0.5%	100	48.6	28.1	15.4	9.1
0.1%	100	31.6	20.6	9.6	4.6
0.05%	100	35.3	16.2	7.6	3.7
THESIT					
1.0%	100	31.9	15.6	6.7	3.4
0.5%	100	36.0	17.6	7.6	3.8
0.1%	100	44.1	25.1	12.6	7.4
0.05%	100	28.4	11.1	3.8	2.0

Condition	5 min	75 min	169 min	222 min	260 min
Cationic Detergents					
BDDABr					
0.5%	100	87.7	76.2	78.9	82.6
0.1%	100	72.7	46.1	33.5	25.0
0.05%	100	64.1	34.8	23.7	17.4
CTAB					
0.1%	100	70.7	37.0	24.5	not done
0.05%	100	61.7	32.1	22.0	15.4
DTAB					
1.0%	100	86.6	81.1	83.8	80.6
0.5% (1)	100	90.6	88.0	87.3	80.2
0.5% (2)	100	95.8	90.3	88.0	85.0
0.1%	100	68.0	39.2	27.9	20.1
0.05%	100	48.4	23.1	14.5	9.8
Zwitterionic Detergents					
CHAPS					
1.0%	100	52.7	32.4	18.3	11.2
0.5%	100	54.9	34.6	19.5	12.3
0.1%	100	39.7	19.0	8.6	4.4
0.05%	100	36.3	18.0	7.9	3.8
CHAPSO					
1.0%	100	53.1	33.2	18.6	11.7
0.5%	100	55.1	34.8	19.7	12.4
0.1%	100	39.5	18.5	8.5	4.3
0.05%	100	37.9	17.6	7.5	3.7
Sulfobetaine 3-10					
1.0%	100	72.6	54.9	39.1	27.9
0.5%	100	36.6	18.4	9.3	6.0
0.1%	100	36.4	16.9	6.9	3.4
0.05%	100	36.3	16.9	7.4	3.7

The data demonstrate that for the anionic detergents tested, SDS at concentration 0.05% and deoxycholate at concentrations 0.5% and 0.1% slow the degradation of endogenous ATP in the cell lysate resulting in from about three to

about twenty times more ATP present in the sample after four hours when the detergent was present than when it was absent indicating inhibition of ATPase endogenous to the sample. The non-ionic detergents had little, if any, additional ATP present in the sample after four hours in the presence of the detergent than in the absence of the detergent indicating that these detergents did not inhibit endogenous ATPase. The zwitterionic detergents tested had three to four times more ATP present in the sample after four hours when the detergent was present than when it was absent. The most significant results were seen when cationic detergents were incubated with the cell lysate. BDDABr at 0.5% concentration, and DTAB at 0.5% and 1.0% concentrations, each had at least 25-fold more ATP present in the sample after four hours than samples without these detergents. CTAB at 0.05% concentration had about four times more ATP present in the sample after four hours when the detergent was present than when it was absent.

Example 2 II. Detergents That Inhibit ATPases

This example tested the seven detergents that demonstrated inhibition of ATPase activity in Example 1 herein above at a lower percentage than was previously tested. The experiment was performed as detailed in Example 1. The average relative light unit values and the percent of ATP remaining values are listed below in Table F and G respectively.

Table F Average Relative Light Unit Values

	5 min	75 min	169 min	222 min	260 min
Controls					
Cell Lysate	5296.25	1613.68	334.28	225.95	123.08
ATP + Hepes	22565.95	16238.00	20241.55	19302.50	18528.1
Samples					
0.5% DTAB	5189.8	4564.65	4111.89	4230.51	4267.32
0.02% DTAB	5870.43	1997.09	435.05	329.83	227.72
0.02% BDDABr	6215.32	2686.49	962.85	604.47	429.86
0.02% Sulfobetaine	6120.5	1622.61	291.09	245.55	136.43
0.02% Deoxycholate	5962.61	1694.47	368.11	241.05	135.25
0.01% SDS	13116.20	10753.03	12051.63	11822.03	11900.73
0.002% SDS	5773.39	1574.34	278.67	236.28	128.58

Table G **Percent ATP Remaining**

	5 min	75 min	169 min	222 min	260 min
Condition					
Lysate Control	100.00	30.47	6.31	4.27	2.32
ATP Control	100.00	71.96	89.70	85.54	82.11
0.5% DTAB	100.00	87.95	79.23	81.52	82.23
0.02% DTAB	100.00	34.02	7.41	5.62	3.88
0.02% CTAB	100.00	43.22	15.49	9.73	6.92
0.02% BDDABr	100.00	48.53	21.51	13.18	9.74
0.02% Sulfobetaine	100.00	26.51	4.76	4.01	2.23
0.02% Deoxychol.	100.00	28.42	6.17	4.04	2.27
0.01% SDS	100.00	48.62	25.80	14.20	8.79
0.002% SDS	100.00	27.27	4.83	4.09	2.23

The log of the percent of ATP remaining after original timepoint values from Table E and Table G were plotted on the y axis against time (in minutes) on the x axis. The slope of the line generated by these values in the presence of detergent was divided by the slope of the line generated by the values in the absence of detergent (lysate control) resulting in the Relative ATPase Activity values listed below in Table H.

TABLE H. RELATIVE ATPase ACTIVITY

Relative ATPase Activity		Slope	slope det / slope lysate
Controls:			
Cell lysate (cat & an)		-0.0056	1.000
Cell lysate (zwit & non)		-0.0053	1.000
ATP control (cat & an)		-0.0002	0.030
ATP control (zwit & non)		0.00002	-0.005
ATP control for detergents less than 0.05%		-0.00013	0.02
Anionic:			
SDS	Percent detergent		
	1.00	-----	-----
	0.50	-----	-----
	0.10	-----	-----

	0.05	-0.0006	0.105
	0.01	-0.00385	0.702
	0.002	-0.0064	1.010
Bioterger			
	1.00	-----	-----
	0.50	-----	-----
	0.10	-0.0076	1.366
	0.05	-0.0062	1.113
Deoxycholate			
	1.00	-----	-----
	0.50	-0.0009	0.158
	0.10	-0.0038	0.684
	0.05	-0.0055	0.984
	0.02	-0.0064	1.004
Non-ionic:			
Triton X-100			
	1.00	-0.0061	1.152
	0.50	-0.0059	1.117
	0.10	-0.0047	0.889
	0.05	-0.0065	1.228
BIGCHAP			
	1.00	-0.0038	0.725
	0.50	-0.0041	0.782
	0.10	-0.0051	0.968
	0.05	-0.0056	1.069
Thesit			
	1.00	-0.0058	1.096
	0.50	-0.0056	1.065
	0.10	-0.0045	0.850
	0.05	-0.0068	1.295
Cationic:			
BDDABr			
	1.00	-----	-----
	0.50	-0.0004	0.064
	0.10	-0.0023	0.414
	0.05	-0.0030	0.528
	0.02	-0.0039	0.623
CTAB			
	1.00	-----	-----
	0.50	-----	-----
	0.10	-0.0028	0.507
	0.05	-0.0031	0.561
	0.02	-0.0046	0.718
DTAB			
	1.00	-0.0003	0.057

	0.50	-0.0003	0.055
	0.50	-0.0003	0.048
	0.10	-0.0027	0.480
	0.05	-0.0039	0.690
	0.02	-0.0056	0.884
Zwitterionic:			
CHAPS			
	1.00	-0.0038	0.715
	0.50	-0.0036	0.688
	0.10	-0.0054	1.023
	0.05	-0.0056	1.061
CHAPSO			
	1.00	-0.0037	0.703
	0.50	-0.0036	0.685
	0.10	-0.0054	1.030
	0.05	-0.0057	1.080
Sulfobetaine 3-10			
	1.00	-0.0022	0.417
	0.50	-0.0049	0.921
	0.10	-0.0058	1.109
	0.05	-0.0057	1.077
	0.02	-0.0064	1.009

A relative activity value of 1.0 or greater indicates 100% cellular ATPase activity at the concentration of detergent tested. A relative activity value of 0.5 indicates a two-fold (or 50%) decrease in the level of cellular ATPase activity at the concentration of detergent tested when compared to the ATPase activity level in the absence of the detergent. A relative activity value of 0.2 indicates a five-fold (or 80%) decrease in the level of cellular ATPase activity at the concentration of detergent tested when compared to the ATPase activity level in the absence of the detergent.

For the cationic detergents tested, the reaction conditions which resulted in a 25% or greater decrease in the relative ATPase activity were DTAB at concentrations of 0.05% and greater; CTAB at concentrations of 0.02% and greater; BDDABr at concentrations of 0.02% and greater. Therefore, all cationic detergents tested in this assay at a concentration of 0.05% or greater decreased cellular ATPase activity by 25% or more. For the anionic detergents tested, the reaction conditions which resulted in a 25% or greater decrease in relative ATPase activity compared to

reactions in the absence of detergent were SDS at concentrations of 0.01% and greater and deoxycholate at concentrations of 0.1% and greater. None of the nonionic detergents tested resulted in a 25% or greater decrease in the level of cellular ATPase activity. For the zwitterionic detergents tested, only sulfobetaine at a concentration of 1% or greater was able to decrease the relative ATPase activity by 25% or greater compared to reactions in the absence of detergent.

These values are graphed in Figure 1 (nonionic and zwitterionic detergents) and Figure 2 (cationic and anionic detergents).

Example 3 Stability of Reagent composition Composition (room temp.)

The detergents used for inhibition of endogenous ATPase activity in a sample also affect activity of luciferase. This example was designed to test the stability and functionality of the reagent composition composition ("reagent composition") over time when it comprised different luciferase enzymes and when the ATPase inhibitor was present at a concentration that significantly inhibited the ATPase activity endogenous to the sample as demonstrated in Example 1 and Example 2 herein above. It is ultimately the extended stability of a reagent composition, comprising an ATPase inhibitor and a luciferase enzyme, which provides a composition useful for measuring ATP, in a sample or samples, over an extended period of time. The most preferred luciferase for use in such a reagent composition would be one whose stability is minimally decreased in the presence of an ATPase inhibitor when that ATPase inhibitor is present in the reagent composition at a concentration capable of inhibiting at least 30% ATPase activity endogenous to the sample.

In this experiment, the stability of a reagent composition comprising wild type LucPpy was compared to the stability of a reagent composition comprising LucPpe2m146 at about 23°C (room temperature). The various reagent compositions had varying detergent concentrations. The various detergents tested were those demonstrated in Examples 1 and 2 above to have significant ATPase inhibition activity.

Two solutions were created as listed below. One contained the luciferase, luciferin, MgSO₄, and buffer (reagent composition). The other solution contained media plus ATP (media solution).

Reagent composition:

	50 µg/ml enzyme (LucPpy is Promega catalog #E170A)
	50 mM Hepes buffer (pH 7.0)
	100 mM NaCl
5	1.0 mM EDTA
	0.1% gelatin
	10 mM MgSO ₄
	1.0 mM Luciferin
	Detergent (at various concentrations, see table below)
10	Nanopure water was added to a final volume of 2.5 ml

Media Solution:

	F12/DME media (Sigma D-6905) final volume 15 ml
15	1.0 µM ATP

For each reagent composition, all ingredients except the luciferase enzyme were assembled; the enzyme was then added immediately before the first luminescence reading was taken. Immediately after addition of enzyme to each reagent composition and for various timepoints thereafter, 100 µl aliquots of the reagent composition were added to wells of a 96-well microtitre luminometer plate in triplicate. To these were added 100 µl Media Solution containing the ATP. Luminescence was then immediately read on a Dynex MLX microtitreplate luminometer, 0.5 second reads per well. The average relative light unit values as well as the reaction half lives are listed below in Table I and the percent of original luminescence remaining at each timepoint is listed in Table J below. The timepoint at the top of the column indicates the time at which the first rlu measurement for the samples in that column was read. Times are provided for some samples when their time of measurement varied significantly from the time at the top of the column. Times listed in Table I are the same for Table J. The values for sulfobetaine and for CTAB were generated on different days, they are presented with the control values generated in the same experiment. There was substantial precipitation in the samples

containing 0.5% deoxycholate and slight precipitation in the samples containing 0.1% deoxycholate. This resulted in unreliable measurements for those samples.

Table I. Average Relative Light Units

<u>LucPpy</u>	<i>(at RT, pH 7.0)</i>					
	0.75 min	21 min	39 min	64 min	92 min	
Control (no det)	3620.263	3610.837	3530.333	3421.743	3442.863	
DTAB 0.5%	0.018					
BDDABr 0.5%	0.001					
*Deoxych. 0.5%	4.801	0.012	0.007			
SDS 0.05%	0.007					
	0.75 min	7.5 min	20.5 min	59 min	90 min	
Control (no det)	3238.01	3147.54	3192.85	3155.05	3203.21	
Sulfobet. 1.0%	0.024	0.000				
Sulfobet. 0.5%	737.788	0.084	0.037			
Sulfobet. 0.1%	3291.41	3178.07	3262.17	3074.49	3066.29	
	0.75 min	10 min	36 min	60 min	95 min	
Control (no det)	2311.293	-----	2294.607	2254.490	2196.130	
DTAB 0.1%	0.307	0.009	0.005			
BDDABr 0.1%	0.007					
SDS 0.01%	0.175	0.016				
*Deoxych. 0.1%	19.771	0.180	0.026			
	0.75 min	6 min	20 min	40 min	62 min	88 min
Control (no det)	2844.21	-----	2672.94	2817.67	2869.35	2852.75
*CTAB 0.1%	94.603	0.020				
*CTAB 0.05%	1134.53	0.563	0.015			
			0.099			
*CTAB 0.02%	1869.80	79.719	(16 min)			
	0.75 min	38 min	70 min	94 min	122 min	
Control (no det)	3379.970	3194.540	3085.880	3015.030	2820.330	
DTAB 0.02%	4513.320	3761.940	3363.410	3229.340	3082.030	
BDDABr 0.02%	2894.700	0.035	0.015	0.016	0.011	
Deoxych 0.02%	3199.250	2844.010	2626.260	2496.570	2314.910	
SDS 0.01%	17.584	0.001				
SDS 0.002%	640.290	190.860	84.210	47.210	25.630	

LucPpe2m146 (at RT, pH 7.0)

	15 min	72 min	124 min	190 min	251 min
Control (no det)	27668.0	25171.53	24023.967	23200.600	20771.450
DTAB 0.5%	5.496	3.141	2.769	2.563	2.766
BDDABr 0.5%	2.040	1.140	0.998	0.899	1.042
*Deoxych. 0.5	45.977	229.874	2059.397	1414.397	1342.963
SDS 0.05%	0.018	0.012	0.001	0.006	0.016

	0.75 min	30 min	66 min	123 min	180 min	238 min
Control (no det)	16897.5	16754.97	17594.7	16842.8	16935.5	17598.6
Sulfobet. 1.0%	16897.5	16754.97	7036.0	6653.67	7358.44	6948.05
Sulfobet. 0.5%	13447.0	13597.97	14186.93	12982.20	14348.90	13958.2
Sulfobet. 0.1%	16648.3	17003.0	17849.8	16610.13	17115.63	18131.37

	1.0 min	34 min	65 min	115 min	175 min	238 min	286 min
Control (no det)	27811.33	28665.87	28814.47	26614.43	27752.97	28249.6	27110.13
DTAB 0.1%	20132.47	20574.63	20800.80	19908.30	20760.93	19758.4	19659.10
BDDABr 0.1%	29.71	66.09	62.19	45.18	33.89	34.46	126.90
*Deoxych. 0.1%	5150.43	5031.12	6855.67	6340.45	7347.09	6801.23	7472.54
SDS 0.01%	24.46	27.85	10.77	6.45	2.02	2.44	0.62

	1.0 min	37 min	67 min	116 min	177 min	243 mi
Control (no det)	16578.6	15270.1	15710.6	16272.3	17085.8	17163.7
*CTAB 0.1%	1047.8	5.3	5.2	6.2	6.0	5.7
*CTAB 0.05%	11992.5	301.5	131.7	4219.7	16910.8	17340.0
*CTAB 0.02%	11019.8	2051.7	1087.4	6117.8	16020.8	16368.5

	1.0 min	34 min	65 min	115 min	175 min	238 min	286 min
Control (no det)	27811.33	28665.87	28814.47	26614.43	27752.97	28249.6	27110.1
DTAB 0.02%	28730.17	28596.30	28651.97	26062.30	27941.73	27677.9	27808.3
BDDABr 0.02%	26548.60	26272.87	25766.43	24155.00	25891.70	24959.1	24510.1
Deoxych. 0.02	24307.30	24639.00	24717.97	23158.37	24655.43	24320.6	24303.9
SDS 0.002%	24265.83	24213.97	24725.73	22654.87	23856.73	23425.5	23275.6

*ppt indicates that the detergent precipitated in the sample

Table J Percent of Luminescence Remaining

LucPpy (at RT, pH 7.0)

Control (no det)	100.00	99.74	97.52	94.52	95.1
DTAB 0.5%	100.00				
BDDABr 0.5%	100.00				
Deoxych. 0.5%	100.00	0.25	0.15		(ppt)

SDS 0.05%	100.00						
Control (no det)	100.00	97.2	98.6	108.5	97.	98.9	
Sulfobet. 0.5%	100.00						
Sulfobet. 0.1%	100.00	95.8	99.1	93.4	93.		
Control (no det)	100.00	nd	99.28	97.54	95.0		
DTAB 0.1%	100.00	2.93	1.55				
BDDABr 0.1%	100.00						
SDS 0.01%	100.00	9.14					
Deoxychol 0.1%	100.00	0.91	0.13				
		-					
Control (no det)	100.00	----	94.0	99.1	100.		
CTAB 0.1%	100.00	0.02					Ppt.
CTAB 0.05%	100.00	0.05	0.00				Ppt.
CTAB 0.02%	100.00	0.09	0.03				Ppt.
Control (no det)	100.00	94.51	91.30	89.20	83.4		
DTAB 0.02%	100.00	99.53	74.52	71.55	68.2		
BDDABr 0.02%	100.00	0.00	0.00				
Deoxych. 0.02%	100.00	88.90	82.09	78.04	72.3		
SDS 0.002%	100.00	29.81	13.15	7.37	4.0		
<u>LucPpe2m146</u> (at RT, pH 7.0)							
Control (no det)	100.00	90.98	86.83	83.85	75.07		
DTAB 0.5%	100.00	57.16	50.39	46.64	50.32		
BDDABr 0.5%	100.00	55.90	48.93	44.07	51.10		
Deoxychol 0.5%	100.00	499.98	4479.22	3076.34	2920.97		Substantial precipitation
SDS 0.05%	100.00	65.68	6.09	35.06	87.64		
Control (no det)	100.0	99.2	104.1	99.7	100.2	104.1	
Sulfobet. 1.0%	100.00	102.0	106.0	100.3	110.9	104.7	
Sulfobet. 0.5%	100.00	101.1	105.5	96.5	106.7	103.8	
Sulfobet. 0.1%	100.00	102.1	107.2	99.8	102.8	108.9	
Control (no det)	100.00	103.07	103.61	95.70	99.79	101.58	97.48
DTAB 0.1%	100.00	102.20	103.32	98.89	103.12	98.14	97.65
BDDABr 0.1%	100.00	222.47	209.32	152.09	114.06	115.98	427.13
Deoxychol 0.1%	100.00	97.68	133.11	123.11	142.65	132.05	145.09
SDS 0.01%	100.00	113.85	44.02	26.38	8.25	9.97	2.53

Control (no det)	100.00	92.11	94.76	98.15	103.06	103.53	
CTAB 0.1%	100.00	0.51	0.50	0.59	0.58	0.55	ppt
CTAB 0.05%	100.00	2.51	1.10	35.19	141.01	144.5	Ppt
CTAB 0.02%	100.00	18.62	9.87	55.52	145.38	148.54	Ppt
Control (no det)	100.00	103.07	103.61	95.70	99.79	101.58	97.48
DTAB 0.02%	100.00	99.53	99.73	90.71	97.26	96.34	96.79
BDDABr 0.02%	100.00	98.96	97.05	90.98	97.53	94.01	92.32
Deoxych. 0.02%	100.00	101.36	101.69	95.27	101.43	100.05	99.99
SDS 0.002%	100.00	99.79	101.90	93.36	98.31	96.54	95.92

Table K Half-life of Luminescence Activity (measured in minutes)

For each concentration of detergent using either luciferase, the stability of the reagent composition can be described as having an activity half-life using the data from Table J. The half-life is determined by applying linear regression to the data, with the logarithm of the relative luminescence values in Table J as the dependent variable, and the time of each measurement as the independent variable. The half-life is then calculated from the linear regression as $\ln(0.5)/(\text{slope})$. Using this method, the stabilities of the reagent composition are listed in Table K; detergent concentration shown as percent (w/v) and values of activity half-life shown in minutes. Where the luminescence activity was less than could be reliably measured, the half-life is shown as "no activity". Some reagent compositions were very unstable, having activity half-lives less than 10 minutes. Because these are difficult to accurately quantitate, they are listed only as "<10". In contrast, some reagent compositions exhibited large stability, having activity half-lives greater than 1000 minutes (i.e., greater than 16 hours). Because the samples were measured for less than 5 hours, accurate determinations of half-lives are difficult and are listed only as ">1000".

In Table K, the values below the horizontal line (in bold) indicate the concentrations of each detergent that inhibited endogenous ATPase activity in Examples 1 and 2 by at least 25%. It is clear that the reagent composition is very unstable when comprising LucPpy and has a concentration of detergent capable of inhibiting at least 25% of the endogenous ATPase activity. In contrast, a reagent comprising LucPpe2m146 and the same detergent concentration generally has moderate to substantial stability. In some cases, luciferase activity was inhibited by

the presence of the detergent, but nonetheless yielded a stable composition. Two detergents, CTAB and deoxycholate, precipitated from the solution during the course of the measurements. This was most notable for CTAB, where LucPpe2m146 was strongly inactivated by the detergent, but slowly regained activity as the detergent precipitated from solution. This behavior made half-life impossible to estimate for the reagent composition containing CTAB. The effect was seen to a lesser extent with deoxycholate.

**Common firefly luciferase
(*P. pyralis*)**

conc.	DTAB	CTAB	BDDABr	Deoxych.	SDS	Sulfobetaine
0.000	>1000	>1000	>1000	>1000	>1000	>1000
0.002					<u>25</u>	
0.010					<10	
0.020	<u>193</u>	<10*	<10	235		
0.050		<10*			no activity	
0.100	<10	<10*	no activity	<10*		877
0.200						
0.500	no activity		no activity	<10*		<u>no activity</u>
1.000						

**Chemostable luciferase
(Ppe2m146)**

conc.	DTAB	CTAB	BDDABr	Deoxych.	SDS	Sulfobetaine
0.000	>1000		>1000	>1000	>1000	>1000
0.002					<u>>1000</u>	
0.010					83	
0.020	<u>>1000</u>	*	>1000	>1000		
0.050		*				
0.100	>1000	*	>1000	>1000*		>1000
0.200						
0.500	265		264	>1000*		<u>>1000</u>
1.000						>1000

*precipitate formed

Example 4 ATPase Inhibition at 22°C and 37°C

Cell lysate was prepared as described in Example 1. The ability of 1% DTAB to inhibit endogenous ATPase (*i.e.*, ATPase present in a sample) was measured in a complete reagent composition over time at both 22°C (room temperature) and 37°C. Three cell lysate samples were prepared. Sample 1 contained 4.0 ml L929 cell lysate plus 4.0 ml 25 mM Hepes, pH 7.5. Sample 2 contained 4.0 ml L929 cell lysate plus 4.0 ml buffered detergent solution (40 mM Citrate (pH 6.0), 110 mM MES (pH 6.0), 450 mM KPO₄ (pH 6.0), 2.0 mM EDTA, 0.2% Mazu DF-204 (PPG Industries), 2.0 mM NaF, 1.0% DTAB and 2% THESIT – final pH of the buffered detergent solution adjusted to 6.0). Sample 3 contained 4.0 ml DMEM/F12 media (no serum) containing 0.1 µM ATP plus 4.0 ml 25 mM Hepes (pH 7.5). The samples were divided in half; half was incubated at 22°C, half was incubated at 37°C. After 10 minutes of incubation in their respective water baths to allow the solution at 37°C to reach that temperature (this point is referred to as time = 10 min.), 100 µl of each sample was transferred independently to a well of a 96-well luminometer plate in quadruplicate. To each 100 µl sample was added 20 µl of a solution containing luciferin (12.5 mM)/luciferase (200 µg/ml LucPpe2m146)/MgSO₄ (50 mM) solution. The resulting relative light units were measured on a Dynex luminometer using 0.5 second reads. This was repeated at several time points out to five hours. The resulting average relative light unit values (Table L) and the percent remaining ATP (Table M) are below.

Table L. Average Relative Light Unit Values

25	<u>Temp.</u>	<u>Time (minutes)</u>					
	37°C	10 min	60 min	110 min	180 min	240 min	300 min
	Sample 1	12371.2	3141.2	930.0	270.7	127.4	55.1
	Sample 2	781.3	792.3	777.5	748.9	728.2	713.4
	Sample 3	2937.2	2815.0	2869.2	2592.3	2046	1953.4
30	22°C	10 min	60 min	110 min	180 min	240 min	300 min
	Sample 1	13073.4	5551.8	2766.29	1121.5	541.8	273.7

Sample 2	606.6	615.5	630.0	615.7	616.4	626.0
Sample 3	2603.4	2527.0	2533.0	2321.9	2052.8	1917.3

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Table M. Percent ATP Remaining

	<u>Temp</u>	<u>Relative light units</u>					
		10 min	60 min	110 min	180 min	240 min	300 min
10	37°C						
	Sample 1	100	25.39	7.52	2.19	1.03	0.44
	Sample 2	100	101.41	99.51	95.86	93.20	91.31
	Sample 3	100	95.84	97.69	88.26	69.68	66.51
15	22°C	10 min	60 min	110 min	180 min	240 min	300 min
	Sample 1	100	42.47	21.16	8.58	4.14	2.09
	Sample 2	100	101.46	103.86	101.5	101.62	103.21
	Sample 3	100	97.07	97.30	89.19	78.85	73.65

Under the conditions of this assay, 1% DTAB resulted in no loss of ATP (*i.e.*, complete inhibition of ATPase endogenous to the sample) at 22°C and minimal loss at 37°C, even when the solution was incubated at the temperature of interest for up to five hours. These data demonstrate reaction conditions for which there is nearly complete endogenous ATPase inhibition, yet in which ATP is stable to at least five hours.

25

Example 5 III. Stability of Reagent Composition

Using the results of Example 4, this experiment was designed to demonstrate the stability of the complete reagent composition at 22°C in comparison to its stability at 37°C as measured by luminescence over time. To generate the complete reagent composition, 10 ml of buffered detergent (36 mM Sodium Citrate, 2 mM EDTA, 20 mM MgSO₄, 2 mM NaF, 1% DTAB, 2% THESIT, 0.2% Mazu, buffered to a final pH

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of 6.0) was added to lyophilized LucPpe2m146, D-luciferin, MgSO₄, CDTA so that the reagent composition had a final luciferase concentration of 80 µg/ml and final luciferin concentration of 5 mM.

The reagent composition was divided in half with one half incubated at 22°C and the other half incubated in a water bath at 37°C. At various timepoints, 100 µl samples were removed from the reagent compositions (in quadruplicate) and transferred to a 96 well luminometer plate. Then, to each 100 µl sample was added 100 µl of 1.0 µM ATP in DPBS (Dulbecco's Phosphate Buffered Saline, Sigma Corp., St. Louis, MO). The plate was shaken for 30 seconds at 700 rpm on an orbital shaker and luminescence was then read on a Dynex MLX microtiter plate luminometer, 0.5 second reads per well. The average relative light unit values are listed below in Table N and the percent remaining ATP and half life values in Table O.

Table N. Average Relative Light Units

Time (min.):	0	23	60	120	185	240	300
22°C	695.4	763.0	741.8	683.8	675.9	664.4	681.4
37°C	----	757.7	722.3	614.4	575.0	544.2	526.1

Table O. Percent Remaining ATP

Time (min.):	0	23	60	120	185	240	300	half-life
22°C	100	109.7	106.7	98.3	97.2	95.5	98.0	>1000 min
37°C	100	108.9	103.9	88.4	82.7	78.2	75.7	573 min

Example 6 DTAB Effect on Stability of Reagent Compositions Comprising Various Luciferases (37°C)

The stability of a reagent composition comprising LucPpe2 luciferase was compared to a reagent composition comprising LucPpe2m90 and a reagent composition comprising LucPpe2m146, in the presence and absence of 0.1% DTAB. These mutant luciferases are thermostable; they are described in detail in PCT application PCT/US99/30925, filed Dec. 22, 1999.

Each enzyme was diluted to 0.05 mg/ml to a final volume of 1.0 ml in either 25 mM HEPES, pH 8.0 or 20 mM citrate, pH 6.0; both with 100 mM NaCl, 1 mM

EDTA, 0.1% gelatin and 5% glycerol. In half of the samples, 0.1% DTAB was added. The enzyme solutions ("reagent compositions") were incubated at 37°C.

At various timepoints, 10 µl of enzyme solution was transferred to a 96-well luminometer plate in triplicate. Then, in triplicate, 100 µl room temperature luciferase assay reagent (1 mM luciferin, 0.2 mM ATP, 10 mM MgSO₄ in 50 mM HEPES, pH 8.0) was added to each 10 µl enzyme solution aliquot, mixed and immediately read in a Dynex MLX microtiter plate luminometer. The ATP in the luciferase assay reagent is at a saturating concentration. The average rlu values are reported, as are the half lives of the reagent composition activity as measured by luminescence (Table P). Half-life was calculated using the formula $\log(0.5)/\text{slope}$ of the data plotted as time (x axis) versus log value of rlu. The time zero is actually about 2-3 minutes after the mixing of enzyme and substrate; this could account for the lower numbers in the presence of DTAB at time 0 than in the absence of DTAB.

Table P. Effect of DTAB on various luciferases' activity

Enzyme/time (min)	Average rlu over time (min)			
	pH 6.0	pH 6.0 + DTAB	pH 8.0	pH 8.0 + DTAB
LucPpe2				
0	18655.25	2372.31	22134.0	7048.95
29	1854.83	0.099	11773.67	0.161
59	206.69	0.08	5070.62	0.034
Half life (min)	9.1	4.0	27.7	3.4
LucPpe2m90				
0	20031.03	16263.53	15795.17	22401.4
59	18453	15535.4	15510.77	15332.67
123	15966.03	13421.5	13735.67	12383.75
183	15546.4	14061.8	13271.05	11271.25
239	14519.63	11924.03	11115.13	9551.65
Half life (min)	510.5	580.1	487.5	207.1
LucPpe2m146				
0	7685.01	5945.34	6652.84	6445.57
61	7077.29	5989.65	6577.91	6214.56
125	5507.01	3754.71	5192.73	4018.92
183	6144.94	4839.58	5476.86	4020.56
237	6471.76	4951.0	5174.22	3734.59
Half life (min)	820.8	682.6	595.5	268.0

*time zero is about 2-3 minutes after mixing of enzyme and substrate

5 **Example 7. Enhanced Duration of Luminescence and Effects of Various Media and Sera on ATP Measurement**

In some embodiments, the compositions of the invention were added to intact cells to lyse them, and then ATP detected. In other embodiments, conditioned culture media were themselves assayed for ATP. However, the various components of media, such as buffers, sugars, amino acids, pH indicators, salts, *etc.*, as well as the

various factors found in serum (equine, bovine, *etc.*) may inhibit luciferase activity. This example demonstrates the effect of cell culture media and sera in the presence of the ATPase inhibitor DTAB on the reagent composition and on the duration of luminescence (referred to herein as “signal stability”) when the reagent composition is combined with a sample supplying ATP.

The following reagent composition was prepared: 40 mM Citrate buffer (pH 6.0), 110 mM MES buffer (pH 6.0), 0.2 mM EDTA, 100 µg/ml Luciferase (LucPpe2m146, diluted from 37.8 mg/ml stock solution), 5 mM luciferin, 300 mM NaCl, 20 mM MgSO₄, 0.05% Mazu DF-204, and varying concentrations DTAB as listed in Table Q below. The luciferase-luciferin reaction was initiated by combining 100 µl of the reagent composition with 100 µl cell media with serum, varying final concentrations of DTAB (as indicated below in Table Q) and 1.0 µM ATP was added to each reaction plus or minus 10 µM sodium pyrophosphate in wells of a 96-well microtiter luminometer plate; each experimental condition was prepared in triplicate. At various times after initiating the reaction, rlu values were recorded using an Orion microplate luminometer (Berthold Detection Systems; Pforzheim, Germany). Average rlus and signal stability (measured in terms of its half-life) are reported in Table Q. In all media tested, the DTAB in the presence of Ppi resulted in a longer half-life than did the DTAB in the absence of the Ppi. The type of media used in the assay did not contribute significantly to signal stability variation. The signal stability half life was calculated from the time 0 (A) and from time 10 min as the original value (B). The Ppi decreased luminescence about ten-fold or more.

Table Q. Effects of media and sera on luciferase-luciferin reaction

Average relative light units over time (min)								Signal stability $t_{1/2}$ (hr)	
Conditions ¹	0	10	30	65	120	180	325	A	B
DMEM + 10% FBS + ATP +									
0.50% DTAB	204771	223493	187757	146766	104150	72609	32307	1.9	1.9
0.55% DTAB	52107	59799	51285	42155	32891	24137	12031	2.4	2.3
0.45% DTAB/Ppi	4989	4723	4053	3743	3611	3514	3188	9.6	11.4
F12/DME + 10% FBS + ATP +									
0.50% DTAB	13467	13311	11348	9953	8127	6538	3793	3.0	3.0
0.55% DTAB	6847	6952	6013	5581	4891	4329	3207	4.9	5.0
0.45% DTAB/Ppi	1467	1342	1107	1047	1017	1036	937	10.6	14.2
F12/DME + 10% HS + ATP +									
0.50% DTAB	88405	82645	70746	58749	44677	33353	17414	2.3	2.4
0.55% DTAB	36615	36669	31348	27979	23778	19955	13539	3.8	3.8
0.45% DTAB/Ppi	6124	5611	4981	4398	4163	3961	3553	7.7	9.0
RPMI + 10% FBS + ATP									
0.50% DTAB	44179	43664	35909	26501	16951	10153	3268	1.4	1.4
0.55% DTAB	21388	22863	19631	16848	12968	9661	5080	2.5	2.5
0.45% DTAB/Ppi	3284	2879	2599	2381	2285	2243	2099	10.4	13.6

Example 8. Cell Number Correlates with Light Output

This experiment demonstrates that luminescence generated by use of the reagent composition in the method of the invention invention directly correlates with viable cell number. A simple correlation between known living-cell numbers and experimentally-determined luminescence was established.

Jurkat cells (ATCC, CRL-1990) were grown in 5% CO₂/95% air, 100% humidity at 37°C and maintained in RPMI media (Sigma, R-8005) containing 10% FBS (Hyclone #SH30070), 1X non-essential amino acids (Hyclone SH30238) and 1 mM sodium pyruvate (Hyclone #SH30239). Cells were suspended at 5×10^5 /ml in fresh complete medium, and 1:2 serial dilutions were prepared. Then, 100 µl of the cell dilutions were added to wells of a 96-well microtiter plate, resulting in 0 – 50,000 cells/well. Quadruplicate replicates were prepared. The plate was then incubated at 37°C, 5% CO₂ for 45 minutes. The plate was then equilibrated at 22°C for 30 minutes. Then 100 µl reagent composition (40 mM Citrate buffer (pH 6.0), 110 mM MES buffer (pH 6.0), 2 mM EDTA, 450 mM KPO₄, 0.4% Prionex, 80 µg/ml Luciferase (LucPpe2m146, diluted from 37.8 mg/ml stock solution), 5 mM luciferin, 2% THESIT, 20 mM NaF, 20 mM MgSO₄, 0.2% Mazu DF-204, 1.0% DTAB), was added to each well, the plate was gently shaken for 2 minutes, and incubated for 10 minutes on a Dynex MLX plate luminometer. The light output was then read in 0.5 second summed interrogations. The resulting average rlus are reported herein below in Table R.

Table R. Correlation of luminescence with cell number

Cells/well	Luminescence (rlu)	standard deviation
0	0.07	0.015
49	1.96	0.233
98	3.27	0.460
195	6.71	0.307
390	12.34	0.356
781	23.53	0.367
1562	47.12	1.583
3125	91.77	1.156
6250	171.93	0.812
12500	346.26	10.739
25000	672.79	7.322
50000	1279.75	14.683

Example 9. Lymphoid Cells tested with NaF

In some cells, such as lymphoid cells (*e.g.*, Jurkat), an increase in luminescence over time in the presence of the reagent composition solution is observed. While the underlying mechanism of this increase in luminescence is not known, it is postulated that it results from the functioning of ATP-generating enzymes in this cell-type. The activity of such enzymes, if left unchecked, will result in an over-estimation of ATP in a sample at the time of the assay. This experiment was designed to test the effects of sodium fluoride on luminescence when using lymphoid cells. The experiment also demonstrates the enhanced duration of luminescence produced by the LucPpe2ml46 in the composition and methods of the invention.

Jurkat cells (ATCC, CRL-1990) were grown in 5% CO₂/95% air, 100% humidity at 37°C and maintained in RPMI media (Sigma, R-8005) containing 10% FBS (Hyclone #SH30070), 1X non-essential amino acids (Hyclone SH30238) and 1

mM sodium pyruvate (Hyclone #SH30239). Cells were plated at 0, 12500, 25000, and 50000 cells/well in 100 μ l of media in a 96-well microtiter luminometer plate. Quadruplicate replicates were prepared. To each of these wells was added reagent composition (reagent composition = 40 mM Citrate buffer (pH 6.0), 110 mM MES buffer (pH 6.0), 0.2 mM EDTA, 0.2% Gelatin, 100 μ g/ml Luciferase (LucPpe2m146, 5 diluted from 37.8 mg/ml stock solution), 100 μ M luciferin, 300 mM NaCl, 20 mM MgSO_4 , 0.05% Mazu DF-204, 0.6% DTAB). In addition, all but the "no KPO_4 " control sample contained 60 mM KPO_4 buffer (pH 6.0). Various concentrations of NaF were then added to the above solution to final concentrations of 0, 1.0, 2.0, 4.0, 10.0 mM; one condition had 10.0 mM NaF but without KPO_4 . 10

Total reaction volume per well was 200 μ l, consisting of 100 μ l cells plus media and 100 μ l reagent composition containing KPO_4 and/or NaF. The light output was taken at various times on a Dynex microtiter plate luminometer at a 0.5 second read time. The resulting average rls from quadruplicate wells and calculated signal 15 stabilities as measured by their half-life values are reported in Table S.

The data demonstrate that the addition of NaF can inhibit the luminescence increase seen when using Jurkat cells in a method of the present invention.

Table S. Effect of NaF on Jurkat cell luminescence

Cells/ Well	Average rlu over time (min)							$t_{1/2}$ (hrs)
	0	30	85	130	220	255	285	
Control								
0	2.84	2.77	3.28	4.30	3.98	4.00	3.97	-
12500	355.70	370.90	420.87	470.88	508.06	523.80	536.11	nc*
25000	761.86	857.57	1174.30	1599.85	2709.75	3099.69	3276.71	nc
50000	1409.87	1946.82	5067.54	12596.83	4991.96	3583.77	2978.22	nc
1.0 mM NaF (in the reagent composition)								
0	2.87	2.72	2.76	2.91	2.42	2.37	2.27	-
12500	358.61	341.31	331.08	323.54	271.89	257.06	247.61	8.8
25000	691.68	640.53	611.45	596.87	495.89	463.32	446.32	7.6
50000	1380.16	1268.49	1185.73	1147.33	936.82	862.31	832.15	6.6
2.0 mM NaF								
0	2.80	2.59	2.58	2.57	2.07	2.06	1.95	-
12500	348.16	333.48	323.75	317.48	258.43	251.90	239.40	8.6
25000	679.02	631.69	603.07	589.08	472.37	455.25	433.54	7.3
50000	1340.22	1239.83	1156.03	1111.04	873.26	829.87	781.80	6.1
4.0 mM NaF								
0	6.55	7.65	15.30	33.49	15.12	11.87	10.43	-
12500	367.69	346.05	335.27	331.07	275.13	259.58	251.79	8.6
25000	691.41	634.08	604.37	587.41	476.36	453.66	436.38	7.2

Cells/ Well	0	30	85	130	220	255	285	
50000	1378.13	1277.41	1195.56	1139.99	883.49	853.43	813.31	6.1
10.0 mM NaF								
0	6.55	6.20	6.47	7.87	5.52	5.27	5.13	-
12500	364.79	343.44	331.48	326.32	271.64	256.88	248.30	8.5
25000	753.29	677.94	635.67	617.77	496.08	471.66	450.76	6.6
50000	1442.08	1324.67	1235.80	1181.84	903.44	870.95	826.48	5.8
10.0 mM NaF, without KPO ₄								
0	5.95	5.65	5.43	5.34	4.19	4.16	3.91	-
12500	409.57	400.10	384.84	371.42	294.12	283.01	267.78	7.3
25000	806.87	785.16	734.44	692.57	516.69	498.99	468.90	5.7
50000	1514.80	1449.30	1340.91	1258.88	889.88	865.24	807.41	4.9

*nc – not calculable due to increase in rlu values over time

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